MINING METHODS AND COSTS AT THE SUNBRIGHT LIMESTONE MINE, FOOTE MINERAL CO., SUNBRIGHT, VA.

By Thaddeus B. Evans and N. A. Eilertsen

* * * * * * * * * * Information Circular 7793

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Thaddeus B. Evans[1/] and N. A. Eilertsen[2/]

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SUMMARY

This information circular is one of a series describing mining methods and costs, being published by the Bureau of Mines. The Sunbright mine of the Foote Mineral Co. at Sunbright, Va., is the southernmost underground limestone mine in the State. It is a comparatively recent operation, and a description of its rapid development to production stage may have particular interest for the limestone-mining industry.

ACKNOWLEDGMENTS

Acknowledgment is made to the executives of the Foote Mineral Company including F. B. Shay, vice president in charge of production, W. B. Towner, general production manager; and to the members of the company staff at Sunbright for their assistance in preparing this paper.

Acknowledgment is also made to T. L. Kesler, chief geologist, Foote Mineral Co., and to Dr. Jean Lowry, Virginia Geological Survey, for assistance in geologic interpretation.

HISTORY OF MINE AND EARLY DEVELOPMENT

In 1951, when the Foote Mineral Co. was developing pegmatite deposits at Kings Mountain, N. C., for production of spodumene concentrate, it became necessary to seek a source of limestone for use in a chemical process for manufacturing lithium salts. As more limestone than spodumene concentrate would be used in processing, it was desirable to find a deposit convenient to rail transportation in an area also suitable for building a lithium reduction plant. Selection of a plant site depended upon three factors; the limestone had to be (1) high-quality stone, (2) within an area of abundant fuel, electric power, and water supply, and (3) centrally located for economic transportation.

The company was attracted to publications of the Virginia Geological Survey; and a noted authority on the limestones of southwestern Virginia, Dr. Byron N. Cooper,[3/] was engaged as a consultant to assist in locating a deposit near a site favorable for industrial development. As a result of this survey, several gently sloping beds of high-purity oolitic limestone occurring at Sunbright (see location map, fig. 1), on the Southern Railway, were found of suitable grade, and an initial purchase of land was made from W. R. Horton.

The original mining operation by Foote was started as a quarry on the outcrop of the lowest and most promising bed, and the first stone was produced in June 1953. As the quarry developed, it became evident that chemical-grade stone could not be economically recovered by surface mining, since it was found at times that the ratio of combined overburden and other impure waste stone to chemical-grade stone was as

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3/ Cooper, Byron N. (professor of geology, Virginia Polytechnic Institute), Industrial Limestones and Dolomites in Virginia, Clinch Valley District: Virginia Geol. Survey Bull. 66, 1945, 259 pp.

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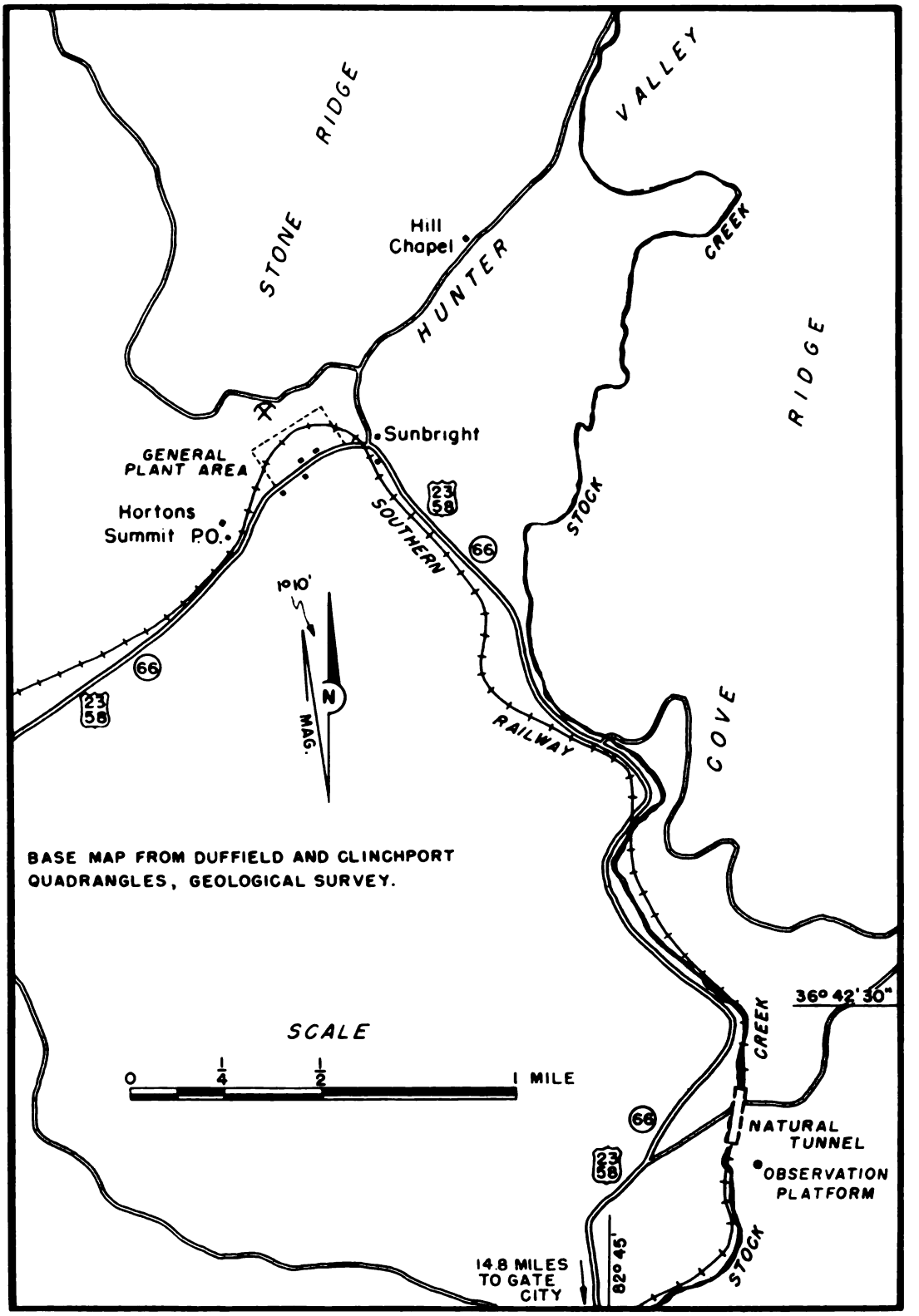

Figure 1. - Location of Sunbright limestone mine, Scott County, Va.

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high as 4:1. Meanwhile, entry to the deposit was made for underground mining, and by the end of October 1953 all the limestone required for plant operation came from underground workings.

Limestone is mined on a royalty basis of 3 cents per ton for usable material accepted for plant consumption, which is exclusive of fines rejected by screening and waste rock sorted in the mine and discarded on the surface dump. Production records from the start of mining in June 1953 through December 1955 are shown by a chart (fig. 2).

DESCRIPTION OF DEPOSIT

The limestone currently being mined at Sunbright and referred to as the "lower bed" is one of a group of interbedded limestone and siltstone deposits outcropping on a hillside at the southwestern end of Stone Ridge west of the Hunter Valley fault. The group is part of the Newman series of Mississippian age and according to Butts[4/] is correlated with the Greenbrier limestone of West Virginia.

Stratification within this series is quite obscure and difficult to trace from one borehole to another. It is suspected that some of the less pure beds are thin lenses that disappear as they overlap with limestone of different character. The purer beds are thicker and oolitic. Several of these beds are present in the stratigraphic column containing limestone of high purity, but magnesia and silica tend to increase toward the bottom of the beds.

The "lower bed" is 40 to 60 feet thick over a large part of the property, but thins out updip along the west side. The minable portion contains less than 2-1/2 percent of magnesium carbonate. As the mine progresses farther into the formation, some change in character is noted, as the oolites become less pronounced from the top toward the bottom of the bed. This change in phase, which also is accompanied by a slight color change from white to gray, requires additional study. However, the stone being mined from the "lower bed" contains abundant fine, clearly visible, crystalline calcite, which is a mark of high-quality stone. It is of medium hardness and brittle. The oolitic limestone breaks with a conchoidal fracture, and the fine, hairlike, incipient fractures in stone disturbed by blasting attest to its brittleness. No jointing is noted in the deposit. The formation has been warped by regional thrust, and the "lower bed" is gently undulated. It dips about 12° southeast and is overlain by a dark gray-black, laminated or layered, impure limestone 2 to 6 feet thick, with smooth but nubbly partings due to stylotic structure. Some of the partings are not completely healed with clay or calcite. Tension cracks and shears usually are cemented with fine calcite. A more compact dolomitic limestone bed above this layer offers strong support and good anchorage for roof bolts where bolting is found necessary.

The "lower bed" contains numerous but minor structural irregularities due primarily to warping. Tension fractures and fissures, which occur with no definite pattern, have been recemented with calcite. Near-bedding faults, in the vicinity of the upper contact of the bed, cover a wide area in the present interior of the mine. When undisturbed by mining the fault plane forms a good roof. Corrugations in the fault plane, which also rolls with the curvature of the warp in the bed, strike N. 30° - 50° W.

4/ Butts, Charles, Geology of the Appalachian Valley of Virginia: Virginia Geol. Survey Bull. 52, part 1, 1940, pp. 405-406.

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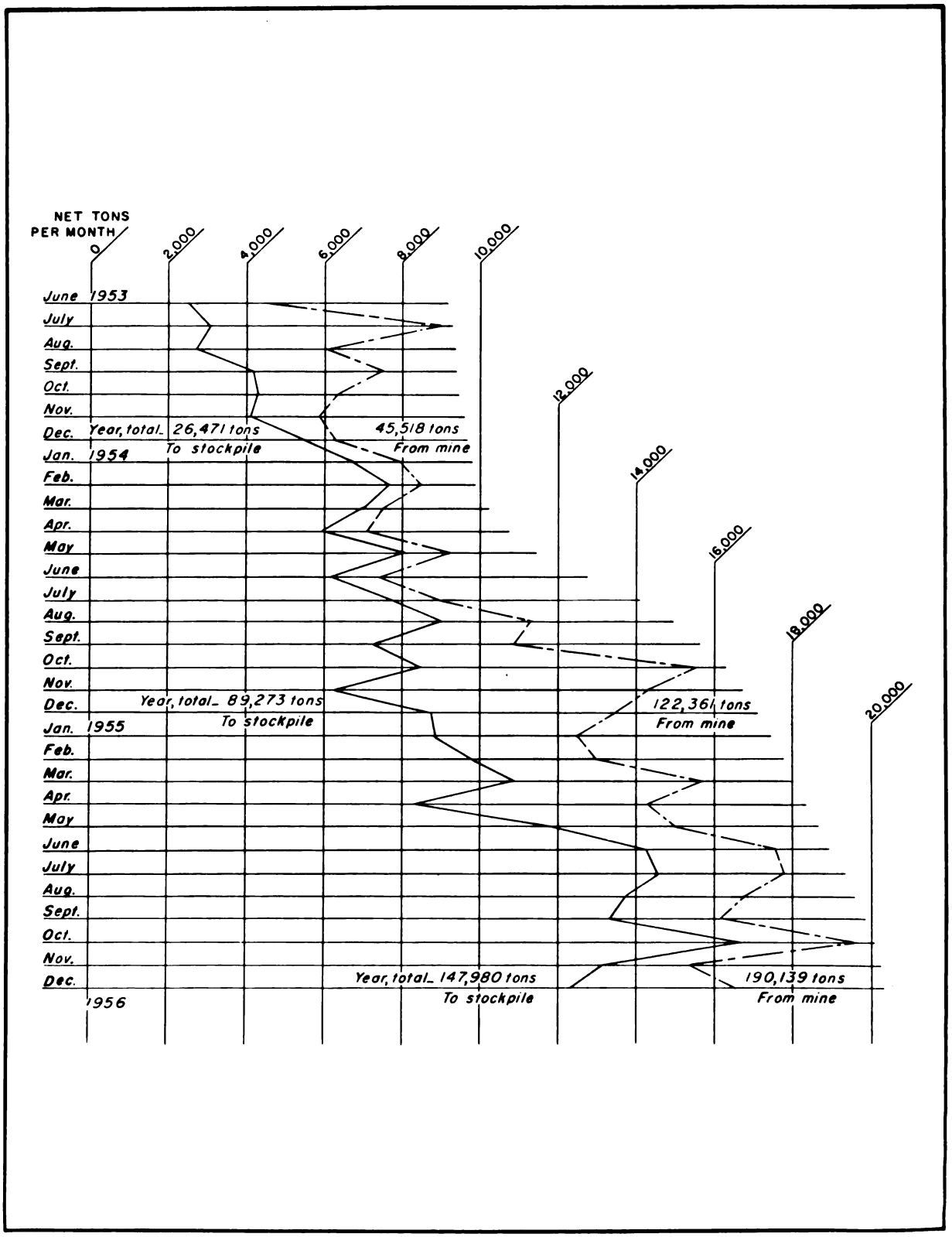

Figure 2. - Limestone-production record through calendar year 1955.

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The deposit is cut by solution cavities formed by the dissolving action of circulating ground waters along fractures. Open fissures encountered by mining are nearly vertical and range from a few inches to over 1 foot in thickness. They are lined or filled with red-brown clay or silt. Larger caverns are found along the upper contact of the bed where both the oolitic stone and the impure limestone above the lower bed have been dissolved. These larger caverns are generally elongated parallel to the bedding. Smaller caverns (some nearly circularlike pipes 2 to 3 feet in diameter) wander in no particular pattern. These ancient watercourses cause local weakness in the roof of mine openings. When large enough to enter, they are mapped by compass surveys and plotted to guide mining operations.

The stone, as mined and blended to average 97 percent $CaCO_3$ and 2-1/4 percent or less $MgCO_3$, has a specific gravity of 2.58 and weighs 4,354 pounds per cubic yard. This is equivalent to 12.4 cu. ft. per short ton in place.

The physical characteristics of the deposit (including shape, thickness and gentle slope) lend themselves to a flat-roof, room-and-pillar mining method.

METHOD OF EXPLORATION

The limestone beds outcrop in several places on the surface, and as they dip under Stone Ridge it was expedient to explore the formation in 1952 by diamond drilling. Holes were spaced 150 to 900 feet apart horizontally; all drilling was vertical with an AX bit, producing core 1-3/16 inches in diameter. In all, 29 holes have been drilled from the surface to the present time. The first period of exploration, involving 12 diamond-drill holes, was under the supervision of Dr. B. N. Cooper. In 1953 and 1954 7 and 10 holes, respectively, were drilled and logged by G. B. Kneass, Foote Mineral Co. geologist stationed at Sunbright. All holes are bottomed in a bed of red mudrock or siltstone that lies about 30 feet below the lower bed of oolitic limestone now being mined. No drilling has been done below the siltstone, which is estimated (from a surface outcrop on the west side of the property) to be at least 40 feet thick.

Thus, in brief, the bed of limestone that is now being mined as an underground operation was first explored by drilling. Its outcrop is about 850 feet southwest of the present mine portal. At the outcrop the limestone is about as thick as it is underground, but when explored and opened as a quarry it was found to contain several dolomitic and siliceous layers from a few inches to as much as 6 feet thick. Diamond drilling indicated that the layers pinch out northwardly, where their absence formed a basis for planning underground mining.

METHOD OF SAMPLING AND ESTIMATING VALUES

Diamond-drill-core logs have been abbreviated and plotted graphically. A typical section of drill hole (see fig. 3) includes a chemical analysis of core that was split and sampled.

Final ore-reserve estimates within the area being drilled are being calculated. The estimate is being made by weighting average analyses to average thickness of bed over the area influenced by each diamond-drill hole. The total tonnage of limestone and average analyses will then be determined by combining weighted units that comprise the minable bed.

Preliminary estimates of ore reserves indicated by diamond drilling and calculated by weighting the core analysis to the tonnage involved amount to several million tons

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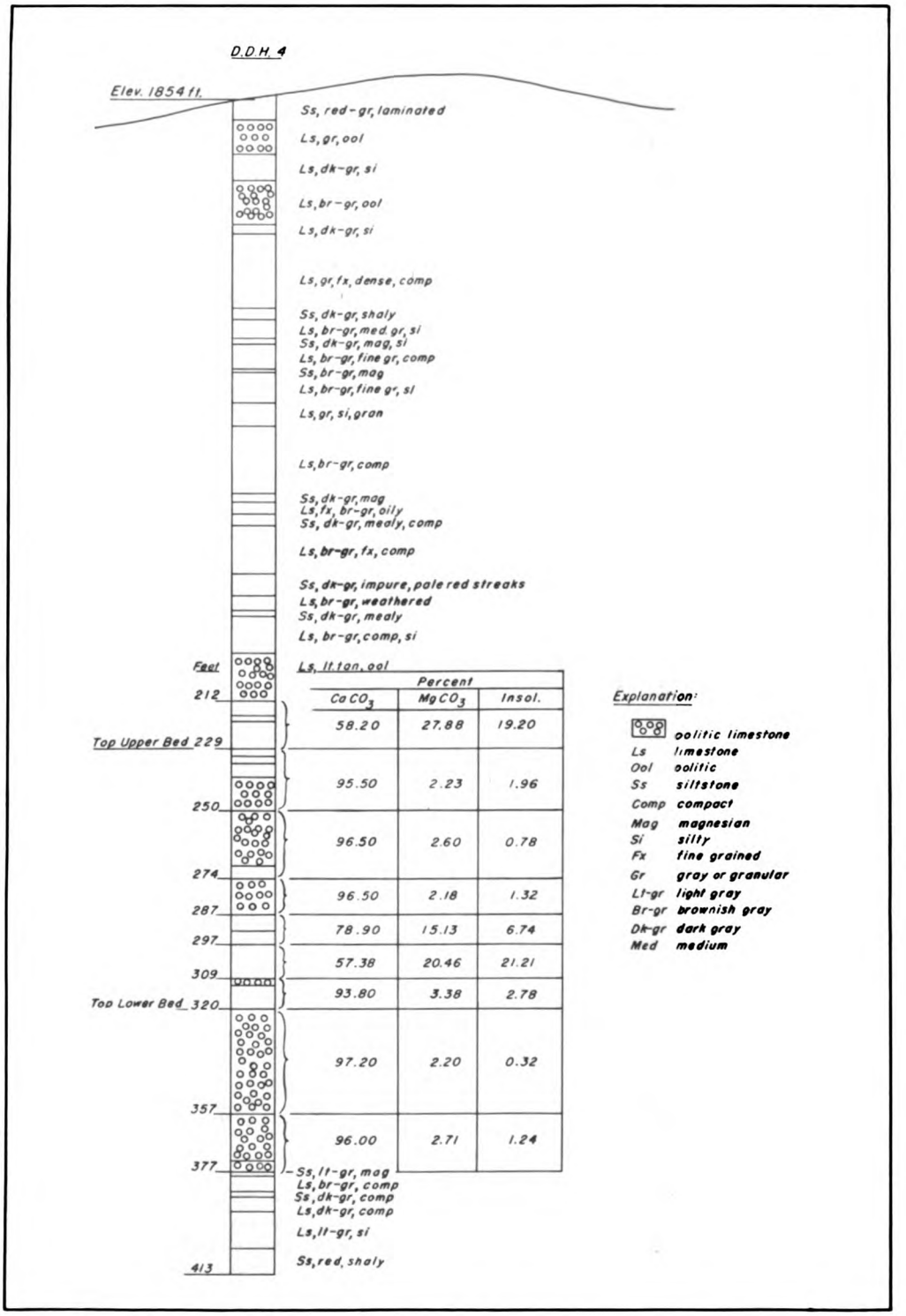

Figure 3. - Stratigraphic column in diamond drill hole 4.

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of high-quality limestone averaging under 2 percent $MgCO_3$. If the grade cut off can be raised to 3 percent $MgCO_3$, the ore reserves may double and may include all of the stone in the oolitic bed over 15 feet of thickness.

To maintain production of high-quality limestone, particular attention is paid to underground sampling.

Development headings underground are rarely sampled, but samples of crushed stone are taken on the surface several times a day between the impact crusher and the storage pile. When the average daily analysis exceeds 2-1/4 percent $MgCO_3$, it becomes necessary to determine the cause and source of contamination. The headings in the mine from which stone was loaded during the day are then chip-sampled vertically down the centerline of the face. The vertically chip sampled interval will vary according to the physical character of the stone, such as change in density, color, or disappearance of crystalline texture.

Limestone under the floors of crosscuts is sampled at average intervals of about 70 linear feet to determine the depth of high-quality stone averaging less than 2-1/4 percent $MgCO_3$. Dry holes are drilled vertically with a jackhammer, using 1-inch hexagonal steel in lengths of 4, 8, 12, and 16 feet. The steel is tipped with a 1-1/2-inch-diameter, 4-point, Liddicoat, detachable-type, knockoff bit. Dust samples are collected for each 2 feet drilled except the first 4 feet of hole, which is taken separately, as it would not be worthwhile to take up less than 4 feet of bottom. Samples are recovered in a permissible dust collector (cost, approximately $275.00) manufactured by United Engineers, Inc., Birmingham, Ala. The apparatus consists essentially of a steel box 18 by 30 by 18 inches deep, containing 7 dry filter elements. Dust as collected on the filters drops into a sliding removable pan 4 inches deep in the bottom of the box. Drilling is done (see fig. 4) through a rubber-lined metal collar attached to a 2-inch-diameter, flexible, rubber suction hose 15 feet long that conducts the dust to the filter box. Suction is provided by injecting compressed air from a branch feeder hose at the junction of suction hose and filter box. A special valve in the injection hose at the junction of hoses near the filter box closes when the hose is removed from the suction line at the box. Samples taken every 2 feet of drilling weigh about 3 pounds. Two samplers working together can drill, collect, and bag 2 feet of sample in 10 minutes.

METHODS OF DEVELOPMENT AND MINING

Quarry Mining

The lower or main bed of limestone crops out on the west side of the property. Mining was begun there as a side-hill quarry in 1953. When the quarry had advanced into the hillside and presented a working face 325 feet long and in 2 places was more than 40 feet high, it was found that the limestone was interbedded with layers of impure stone of lower lime and higher magnesia content, unsuitable for plant consumption. It thus became necessary to consider developing the deposit for underground mining.

Development Required for Underground Mining

A study of the limestone bed explored and mapped by diamond drilling indicated that a portal could be conveniently made 1/4 mile east of the quarry and 500 feet north of the lithium reduction plant. An opencut 25 feet wide on an 8-percent downgrade was started against the sloping hillside in July 1953. High-purity oolitic limestone was encountered at 180 feet in the opencut, where, by coincidence, the

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Figure 4. - Sampling depth of minable stone under floors with a dust collector.

Figure 5. - Mine portal.

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first tunnel round was drilled for a portal. At this point it was possible to mine an opening 25 feet wide by 20 feet high, with 22 feet of protective rock capping over the top of the portal (see fig. 5). Initial drilling in excavating the opencut was done with jackhammer drills, which were replaced by two Worthington UNW-40 wagon drills when tunneling was begun. These wagonframes mount 3-1/2-inch (piston diameter) percussion drills on carriage slides 12 feet long that permit drilling to a depth of 8 feet before steel is changed. Drilling was done with 1-1/4-inch-diameter round steel and 4-point, Liddicoat, detachable (knockoff) bits.

Broken stone was loaded from the opencut with a 1-1/2-yard-capacity, Bucyrus-Erie, diesel-powered shovel laying the material on the lower (left) bank of the cut where a bulldozer could be used to advantage for leveling the pile. When the sides of the opencut were deepened beyond reach of the boom, the Bucyrus-Erie shovel was replaced by an Eimco, diesel-powered, model 104 rocker (overhead-dump) shovel of 1-1/4-cu. yd. capacity. Haulage was provided by two 10-ton-capacity, end-dump, diesel (GM-125-hp.)-powered, Euclid trucks.

Underground Mining (1st-Stage) Room-and-Pillar Method by Tunneling

Tunneling continued from the portal on the bearing of the open cut N. 65° W. at 8-percent downgrade for a linear distance of 65 feet, when it was turned in a general direction N. 8° W., somewhat diagonal to the general dip of the bed. The roof of the tunnel (except for overbreak) was maintained as the upper contact of the deposit.

The mine has been prepared for room-and-pillar mining, with 2 parallel haulageways 35 feet wide by 17 feet high spaced on centerlines 75 feet apart. Facing into the mine (see map, fig. 6), the haulageway at the right is termed the "upper development heading," and that at the left (called the "main heading") is carried for subsequent deepening of the roadbed for use in hauling stone from lower level mining concerned with benching of floors. Parallel crosscuts, at present only driven westerly from the upper development heading and the main heading, are planned for a cross section 17 feet high by 40 feet wide on centerlines 70 feet apart. They are advanced toward the boundary of the deposit and will be stopped when the minable thickness of the bed drops to less than 15 feet. The stone in place between crosscuts forms a series of rib pillars about 40 feet thick, and cross entries 17 feet high by 35 feet wide are made through the pillars on centerlines 65 feet apart. These openings are started when centerlines cross, at which time three tunnel faces are drilled and blasted together. The mine roof is thus eventually supported on pillars 30 by 30 feet in area, comprising 20 percent of the minable area of the deposit.

In earlier development of the mine, rib pillars were planned for a width of 40 to 50 feet to offset the area of roof support robbed by a network of solution cavities or caverns encountered in the southern part of the mine. Some irregularity of pillar arrangement was found necessary because of this defect.

The slope of roadways or floors is governed by the position of the roof, which is maintained as near to the contact of the deposit as is practicable. The upper development heading is driven from horizontal to a down slope as steep as 22-percent grade but averages about 8 percent downgrade, and the roadway pitches and rolls with the warp of the roof. The floors of the westerly driven crosscuts are similarly warped, and tunneling is mostly upgrade following the pattern of the upper contact of the deposit.

Development and mining, in the room-and-pillar method as practiced at Sunbright, are synonymous. Extraction of limestone from the upper part of the bed is completed

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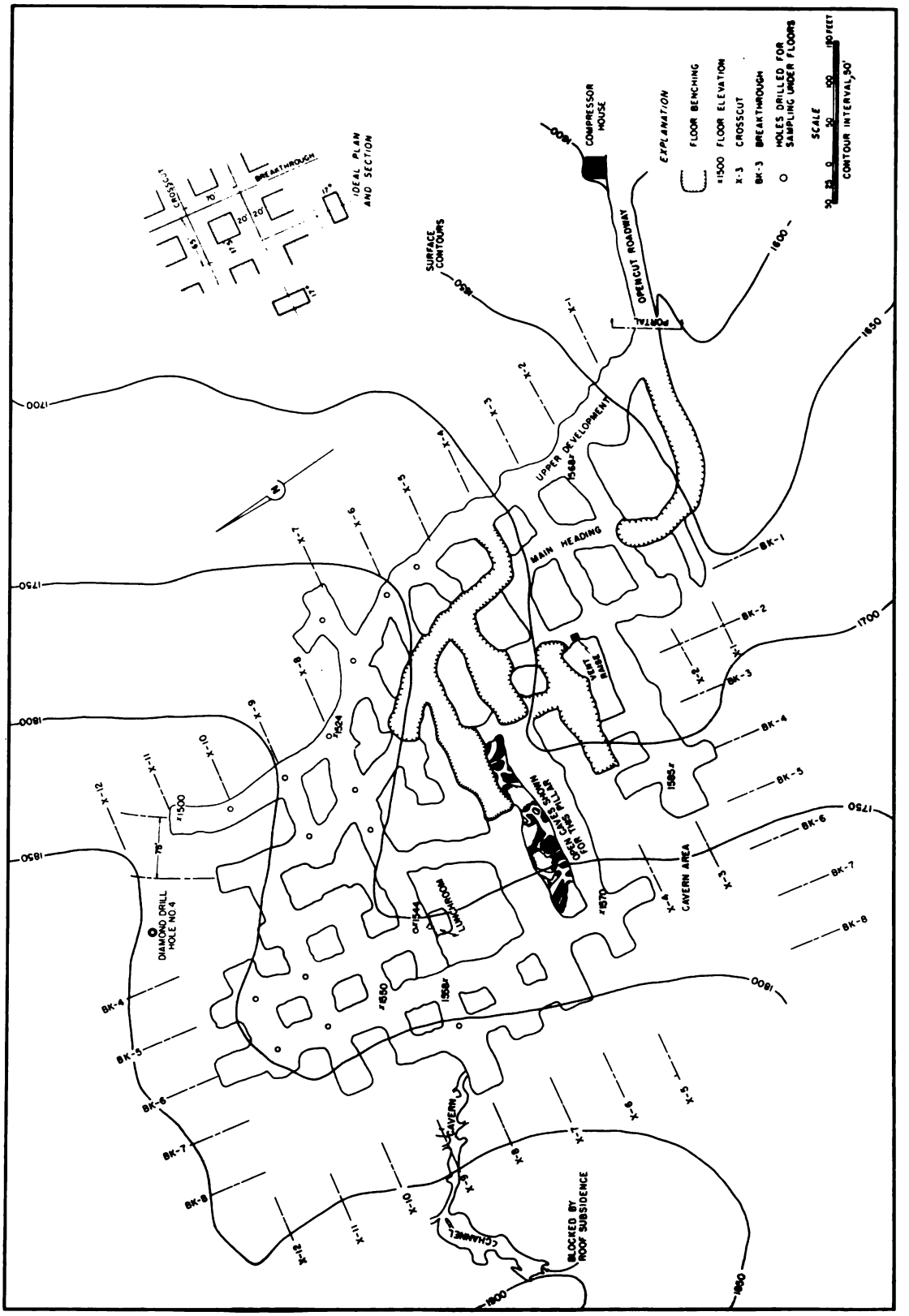

Figure 6. - Plan of Sunbright limestone mine, Foote Mineral Co., Sunbright, Va.

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in the single operation of extending the "heading," whether it is an entry, a crosscut, or a crossentry through a pillar.

The mine is relatively shallow. The capping to the surface does not exceed 250 feet at present. Pillars left for roof support show no indication of being inadequate to withstand superincumbent weight. Surface subsidence is not anticipated and can only take place by failure of the pillars, which is to be avoided if the mine is to be kept open for benching floors, and mining other beds farther up in the stratigraphic column.

At the present depth of workings the mine has no drainage problems. Only a small trickle of water enters the mine as a drip from a surface diamond drill hole. Water used in drilling (approximately 750 gallons per day) and surface runoff which enters the mine through the portal during spells of rainy weather, disappear, and are either drained away by open seams or small caverns under the roadbeds or absorbed by the broken rock after blasting.

It is assumed that the drainage is southeasterly toward the Clinch River or its tributaries.

Underground Mining (2d-Stage) Benching Floors

Assays are plotted on vertical sections, as illustrated in figure 7, and the bottom outline of high grade stone thus determined is used as a guide for bench mining.

Benching of floors in completed crosscuts is begun after the roadbed of the main haulageway is lowered by drilling and blasting to the gradient fixed as the lower limit of mining. The roof above crosscuts is scaled ahead of benching. In the mine area opened at present, the maximum thickness of limestone containing less than 2-1/4 percent $MgCO_3$ is about 32 feet. Greater thickness up to 40 feet may be encountered as the upper level mine-development openings extend farther into the bed.

DRILLING

Tunnel Headings

Tunnel headings were first drilled with wagon drills, but since August 1954 all tunneling, including the upper development heading, main haulageway, crosscuts, and pillar "breakthroughs," has been drilled with a JSP Gardner-Denver, mobile, self-propelled, two-boom Jumbo. Although the machine can be operated by a driller and one helper, it is found advantageous in the Sunbright mine to provide two driller's helpers whose duties include nipping steel, changing steel or bits, assisting by hand signaling when alining drill carriage to drill steel after holes are started, cleaning the bottom face with a hand shovel for drilling toeholes, oiling and greasing the machine, and looking after air hose, water hose, and electric-light cables when the machine is being moved. Weighing 11,750 pounds (shipping weight), complete with drills, the Jumbo (see fig. 8) is mounted on 4 rubber-tired wheels, wheelbase 6 feet, and spread between wheel centers 7 feet. Each pair of sidewheels is propelled by chain drive and powered by a separate 15-hp. air motor. In motion the machine is turned directionally by united forward and reverse movement of each pair of sidewheels. When in position for drilling a heading 35 feet wide, the Jumbo is placed in the center of the tunnel, with the front of the machine about 20 feet back from the face. Two "setups" are necessary for drilling a heading 40 feet wide. The

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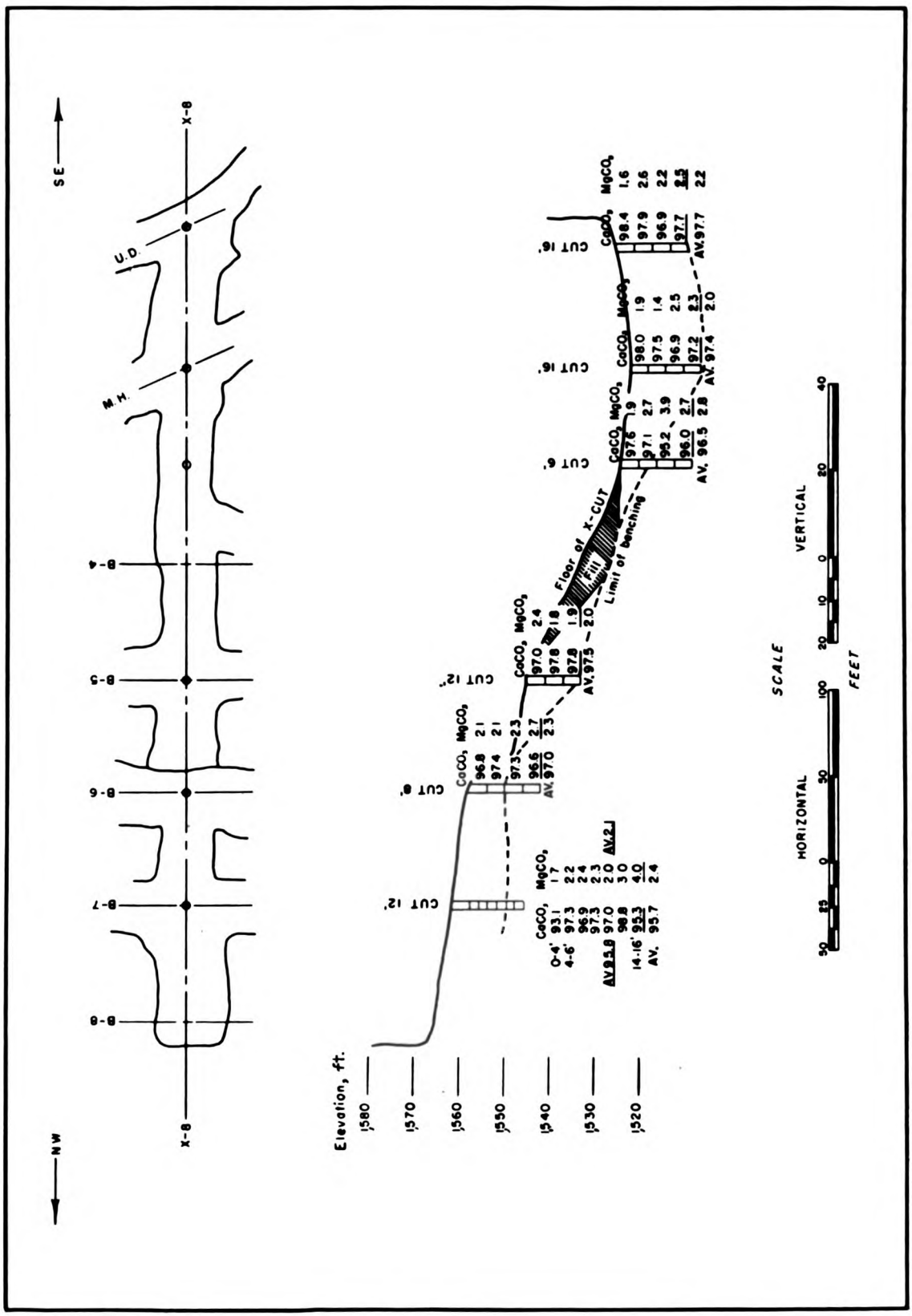

Figure 7. - Vertical section through crosscut X-8. Analysis of dust samples indicating lower limit of benching.

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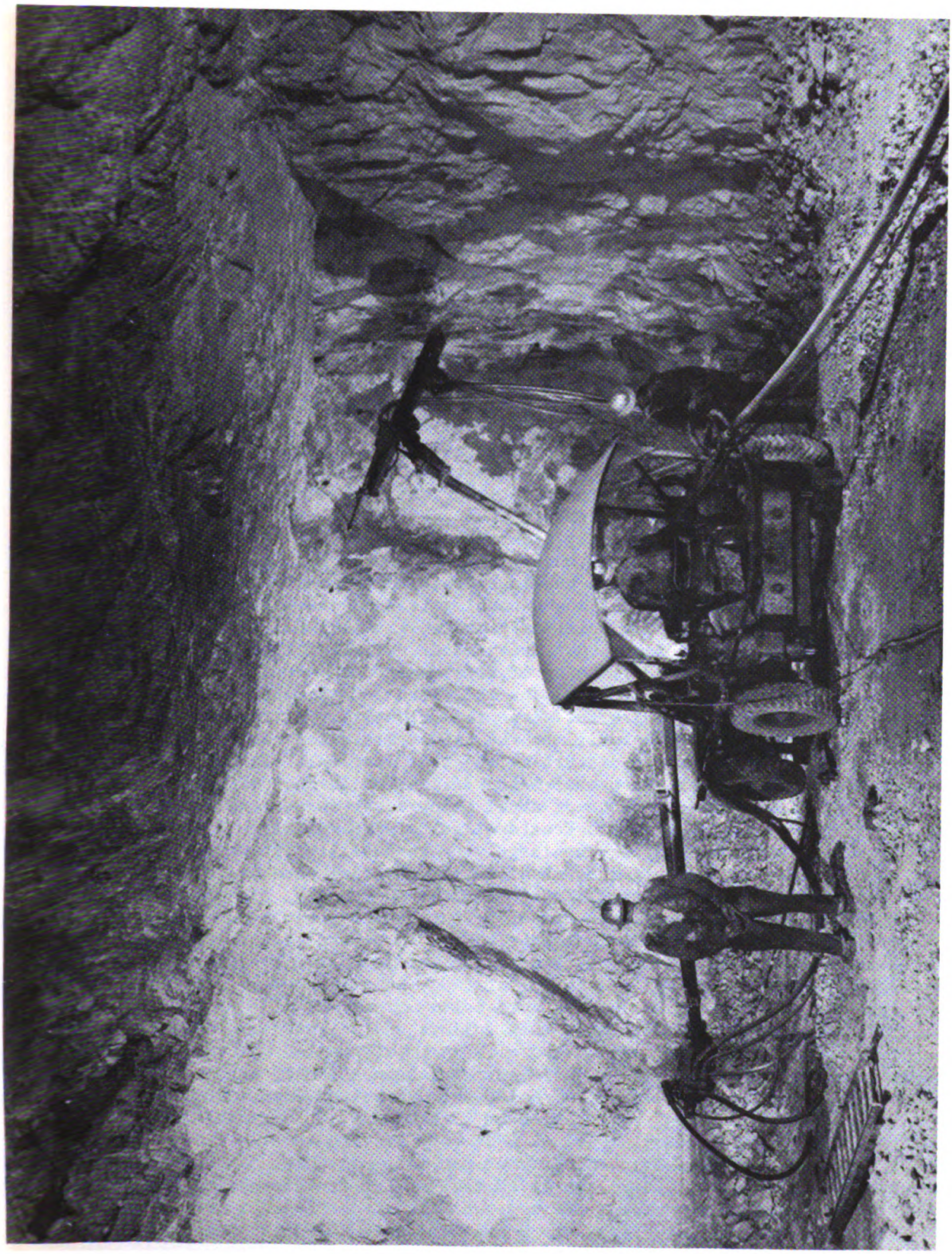

Figure 8. - Jumbo drilling tunnel heading.

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machine is raised from the floor by four hydraulic jacks controlled by levers from the driller's seat. Two booms, each 15 feet long, support drill carriages 17-1/2 feet long. The maximum drilling depth without changing steel is 14 feet. The booms, 3 feet, 9 inches apart, swing and are elevated or depressed, and drill carriages are turned and tipped by lever hydraulic-action control. Drilling is done wet (air pressure, 95 p.s.i.; water pressure, 40 p.s.i.) at the Sunbright mine by Gardner-Denver 3-1/2-inch (piston diameter), type D 93 D, percussion drills mounted on the carriage slides. Compressed air is supplied to a header on the machine by a 2-inch-diameter air hose and carried 4 feet to each side of the Jumbo from the header through 1-1/4-inch-diameter air hose, which also are fitted with air-straining filters.

Each drill machine is advanced by chain feed powered by an air motor mounted under the slide carriage. Except for the changing of steel and bits, every movement of the Jumbo and drills is controlled by the driller without leaving his seat. The length of 1-1/4-inch-diameter round steel used in drilling may range from 10 to 14 feet, but steel is changed only when breakage occurs or the bits need replacement. Both drills are kept in continuous operation. As quickly as one hole is completed, another is started. The elapsed time between the start of withdrawing the drill steel from a completed hole, manipulating the boom, positioning the drill carriage, and starting the next drill hole has been timed as 30 seconds average. As the driller's objective is to complete one heading and move to another without delay, full advantage is taken of short cuts in saving time. For example, when a bit needs replacement, the drill steel and bit are removed from the machine, and a fresh steel with a new bit already attached is quickly inserted. The worn bit is then replaced by a driller's helper at the first opportunity, and the bit-capped steel is made ready for the next change. Three to five headings can be drilled off in an 8-hour shift. The average time required for drilling a heading is 2 hours. It was found that the footage drilled by the Jumbo per shift as compared with the output of two wagon drills was about 650 feet versus 400. The greater drilling capacity of the Jumbo is due largely to the rapid positioning of drills after the completion of a hole and before another hole is started and the long feed carriage that permits use of one steel without changing length for deepening the hole. The Jumbo also has the advantage gained in raising the drill to the higher elevation for near-horizontal drilling, which is necessary in disturbing the roof less upon blasting. The Jumbo offers many advantages over the use of wagon drills for advancing tunnel headings, but it has been found that breakage of steel occurred at an average of 157 feet drilled by the Jumbo as against 303 feet drilled by wagon drills. Breakage generally occurs near the shank and is due largely to instability or sway of drill carriages on the ends of booms, causing misalinement of steel when pressure is applied by the chain feeders. Aside from loss of steel by shortening, the contract cost ($1.00 for reshanking) is more than offset by the many favorable cost features of the Jumbo. The machine has been in operation for 18 months without the necessity of replacing parts or major repairs, except for maintenance and replacement of parts on drills.

Other Jumbo drilling and related data follow:

Size of drill steel.....	1-1/4-in. dia. lugged shank, random length.
Size and type of drill bit.....	1-7/8-in. dia. Cleveland, type CRD, 4-point knockoff, throwaway.
Footage per bit average.....	60
Drilling speed.....	18-22 in. per min.
Depth of holes drilled.....	60 to 10 ft. (standard pattern)
Type of cut.....	"V"
Explosive used per round.....	2 to 3 cases (125 to 150 lb.), standard pattern

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Number of holes per round.....	29 to 38 in 35- and 40-ft.-wide tunnels, respectively
Tons broken per lb. of explosive.	2 to 2-1/2
Cost per bit.....	22 cents
Cost per ft. of drill steel.....	From $1.52 for 10-ft. length to $1.42 for 14-ft. length
Cost per lb. of explosive.....	Approximately 31.6 cents
Cost of millisecond-delay electric detonators, 12-ft. lead wires..	Approximately 2.08 cents for No. 0 to 2.73 cents for 125 millisecond

It has been found that short rounds pull the most efficiently, particularly in areas where the deposit has been affected by fractures and slips. Short rounds also have less damaging effect on the roof; thus the standard round drilled consists of 8-foot-deep cut holes with relief holes 6 feet deep. At times when the loading out of stone from headings lags owing to insufficient crushing capacity or for other reasons beyond control and when the roof is strong and the limestone structure is favorable, a longer round may be drilled where cut holes are 10 feet deep and relief holes 8 feet deep. When caves are intersected, the drilling pattern is changed to suit conditions. Particular care is taken by drillers to blow toeholes clean, because as a rule they are filled with water when the steel is withdrawn. Typical drilling diagrams for tunnel headings are shown in figure 9.

Benches

Benches are drilled from the lower floor level with 2 Worthington-type, UMW 3-1/2-inch (piston diameter) wagon drills. The drill carriage is long enough to permit drilling 8 feet before change of steel is necessary, and it can be elevated to 5 feet above the floor for horizontal drilling. When the height of bench exceeds 9 feet, top rows of holes are fanned upward, and the round may be shortened to suit a reasonable drilling pattern. Bench blast holes have been drilled as deep as 30 feet, which is the maximum length of steel at hand. A typical bench round contains 21 holes (see fig. 10). Drilling is done wet, with the same size steel and bits as for tunneling with the Jumbo. Drilling speed (28 to 30 inches per minute) is higher with wagon drills due to the greater stability and rigidity of drill carriage as compared with the jib-supported carriages on the Jumbo. One 1-7/8-inch-diameter, 4-point bit is usually good for drilling off an entire 16-feet-deep bench, totaling an average 308 feet of drilling.

BLASTING PRACTICE

Tunnel Headings

All charging of explosive and shooting of tunnel headings are done by three blasters on the day shift. Their duties also include assisting with scaling when necessary at the beginning of the shift. Rock particles that may have accumulated in the holes near the collars are fished out with a stiff hooked wire about 30 inches long. Cut holes are loaded and packed to within 15 inches of the collars with explosive, and relief holes are loaded to three-fourths of their length. The explosive used is DuPont Gelex No. 2, 1-1/4- by 8-inch cartridges, 45-percent bulk strength, 120 to 122 cartridges per case of 50 pounds, or of equivalent strength Atlas Gelodyne No. 2. Holes out of reach from the floor are loaded from lightweight, metal, non sparking, magnesium short extension ladders (see fig. 11). The cartridges (carried in leather shoulder bags, capacity 26 cartridges, by the men loading holes) are spirally wrapped for easy tamping, and sandy clay (hand-filled into paper bags carried

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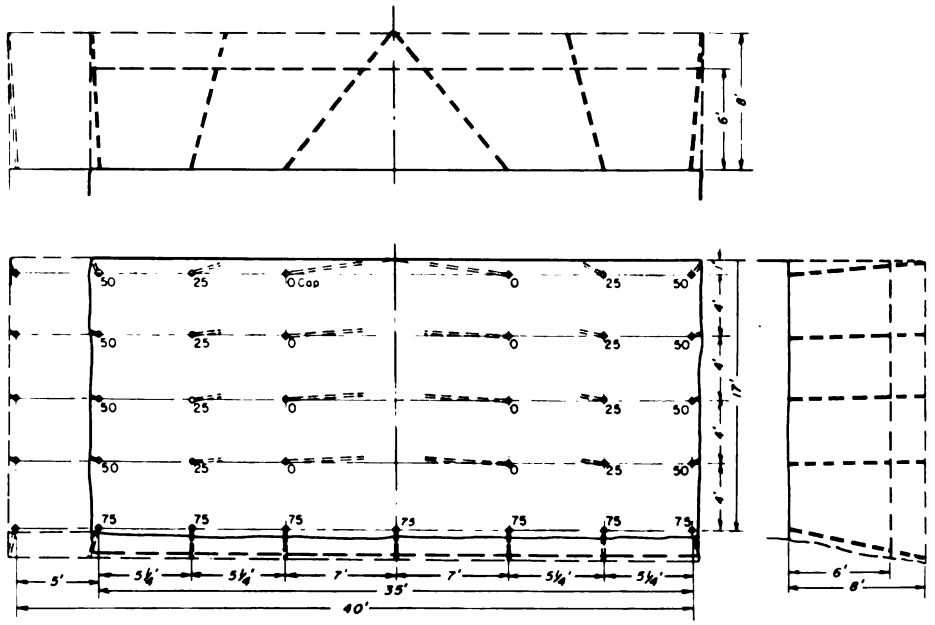
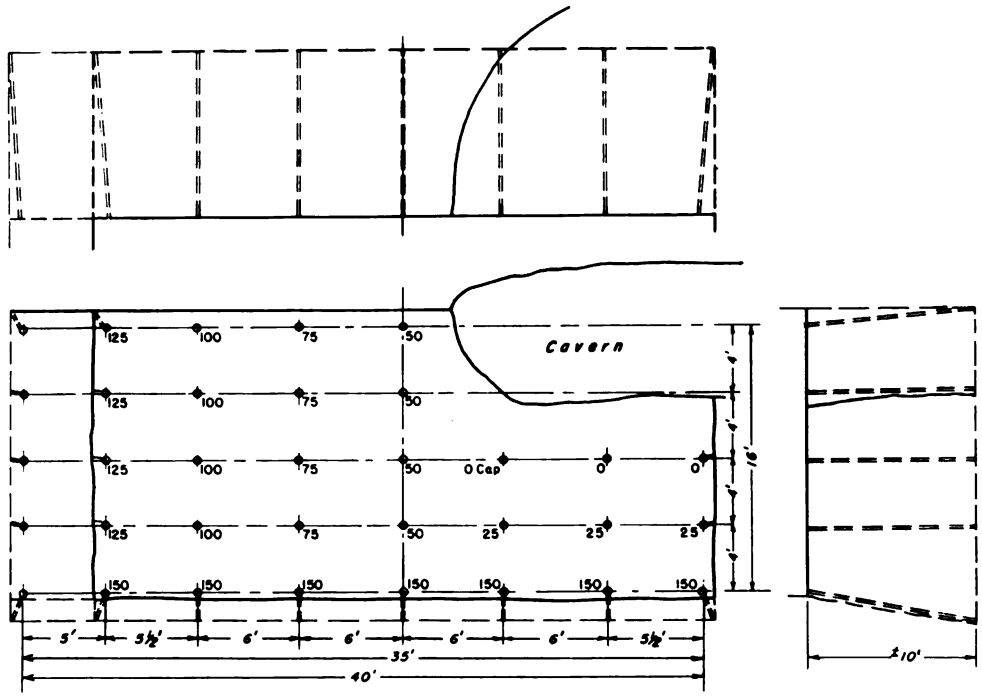


Drilling diagrams for 35-ft. and 40-ft. wide tunnel headings, 6-ft and 8-ft. depth of round. For 40-ft. wide heading, add one vertical row of holes as shown, and explode with 75-millisecond-delay caps. Change lifter holes from 75-to 100-millisecond delays.



Drilling diagram for 35-ft. and 40-ft. wide tunnel heading breaking to a cavern. For 40-ft. wide heading, add one vertical row of holes as shown, and explode with 150-millisecond-delay caps. Change lifter holes from 150-to 175-millisecond delays.

Figure 9. - Typical drilling diagrams and blasting patterns for tunnel headings.

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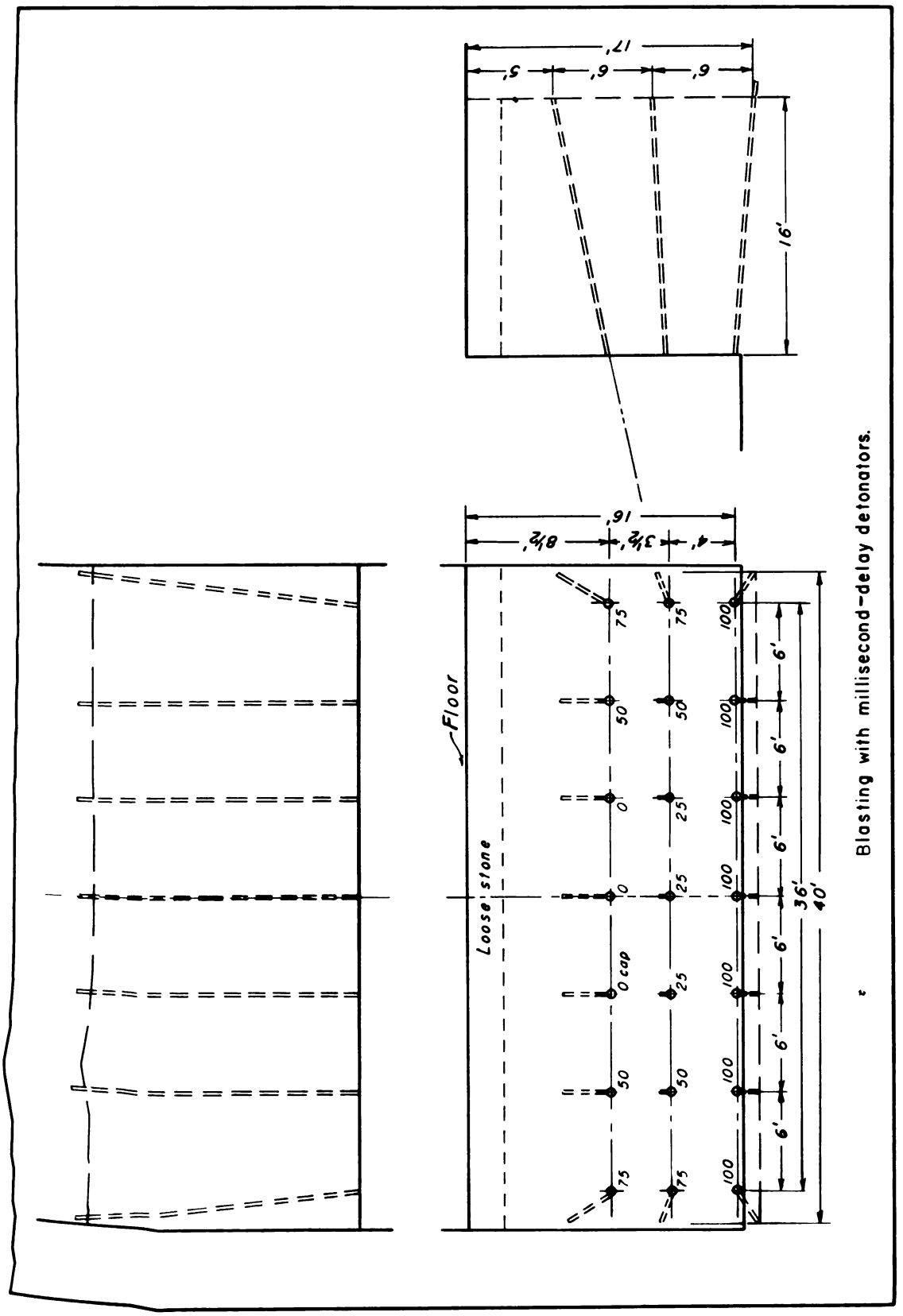

Figure 10. - Typical drilling diagram and blasting pattern for benching floors.

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Figure 11. - Loading explosive from nonsparking magnesium metal extension ladders.

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in hip pockets), is used for stemming. Loading sticks of 1-1/4-inch-diameter oak are cut from stock into convenient lengths for tamping. Detonators (12-foot lead wires) are inserted in the second cartridge pushed into the drill hole (see drilling diagrams, figs. 9 and 10) for millisecond-delay patterns. Lead wires are connected in series to 50 feet of No. 22 blasting wires. Headings are loaded and made ready for shooting by 3 blasters in 40 minutes (fig. 11). They follow the drilling crew and load the tunnel headings as soon as they are drilled out. When not engaged at loading holes, the blasters fill paper bags with stemming material or continue scaling.

At the end of the shift, No. 22 lead wires are connected to a standard, 2-strand, rubber-covered blasting cable paid off from a portable hand reel containing 200 to 300 feet of cable. After the circuit is tested with a galvanometer, the blasting cable is connected to a portable DuPont condenser-discharge machine. Each heading is shot separately, or in multiples of 2 or 3 faces if they are close together. As a rule blasting is done at the end of the day shift, except when occasional demand for stone makes it necessary to blast during the noon rest period.

The portable DuPont condenser blasting machine (see fig. 12) is powered by 6 dry-pack, 6-volt cells capable of detonating 1,800 caps at once. Regularly used once a day, the dry cells have a life of 1 year or more. A pilot light on the hand-carried blasting machine signals a warning when the batteries become weak.

Fragmentation is good, and no blockholing is necessary. The maximum size of stone produced is generally under 18 inches in diameter. Crosscut headings drilled with truncated "V"-cut holes 8 feet long break to a round 5-1/2 feet deep, yielding an average of about 30 truckloads of stone at 8 tons each.

Benches

Bench holes are loaded three quarters full with 1-1/4- by 8-inch explosive cartridges (45 percent bulk strength) without tamping and stemmed with sandy clay in paper bags. Millisecond-delay detonators are used in blasting, and when 12-foot lead wires are too short for deep holes, the length of lead wire is increased by splicing No. 22 lead wire to them. Bench holes are connected in series and shot, after testing with a galvanometer, by the portable blasting machine. Benches are scaled, drilled, loaded, and shot by the wagon-drill crew of two men. Approximately 3.5 tons is broken per pound of explosive in benching, and as much as 1,000 tons of stone will be made available from shooting a bench. The slope of the lower level floor at the foot of benching will conform more to the lower assay limit of under 2-1/4 percent $MgCO_3$ than to the roll and warp of the upper contact of the deposit. Benches are drilled and blasted an average of 3 times in 2 weeks.

LOADING AND TRANSPORTATION

All broken stone from tunnels and benches is mechanically loaded by two Eimco rocker (overhead-dump) shovels of 1-1/4- and 1-1/2-yard capacity, respectively. When both shovels are in use, the larger machine is assigned to work in tunnel headings on the upper mine floor. These shovels, requiring 13 feet, 6 inches and 15 feet, 6 inches, of headroom, respectively, to permit swing of the bucket overhead, are well adapted to the cross section of the mine openings. The flat, rounded, and pointed bottom of the shovel buckets (6 feet, 4 inches, long by 3 feet, 10 inches by 2 feet, 7 inches, deep on the 1-1/2-yard and 5 feet, 6 inches, by 3 feet, 9 inches, by 2 feet, 9 inches, deep on the 1-1/4-yard shovel) are used to advantage in skimming the piles of broken stone after blasting for removing waste rock brought down by roof overbreak. The sticky red clay that falls from the occasional cave or mud seam that

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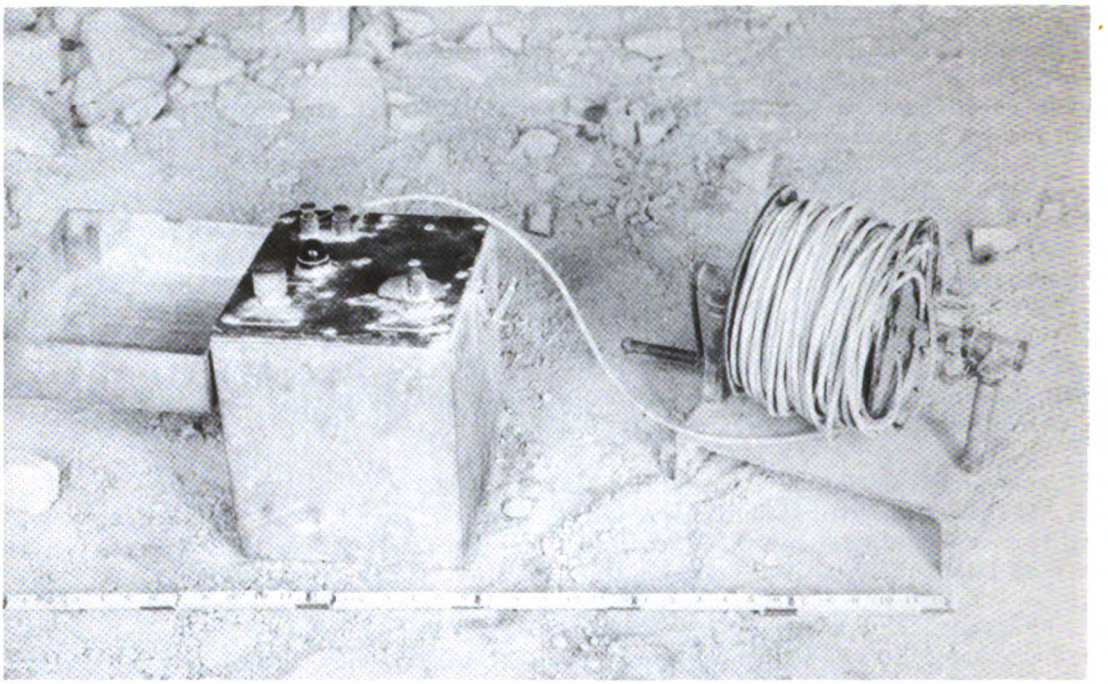

Figure 12. - Portable-condenser blasting machine and reel of rubber-covered copper wire.

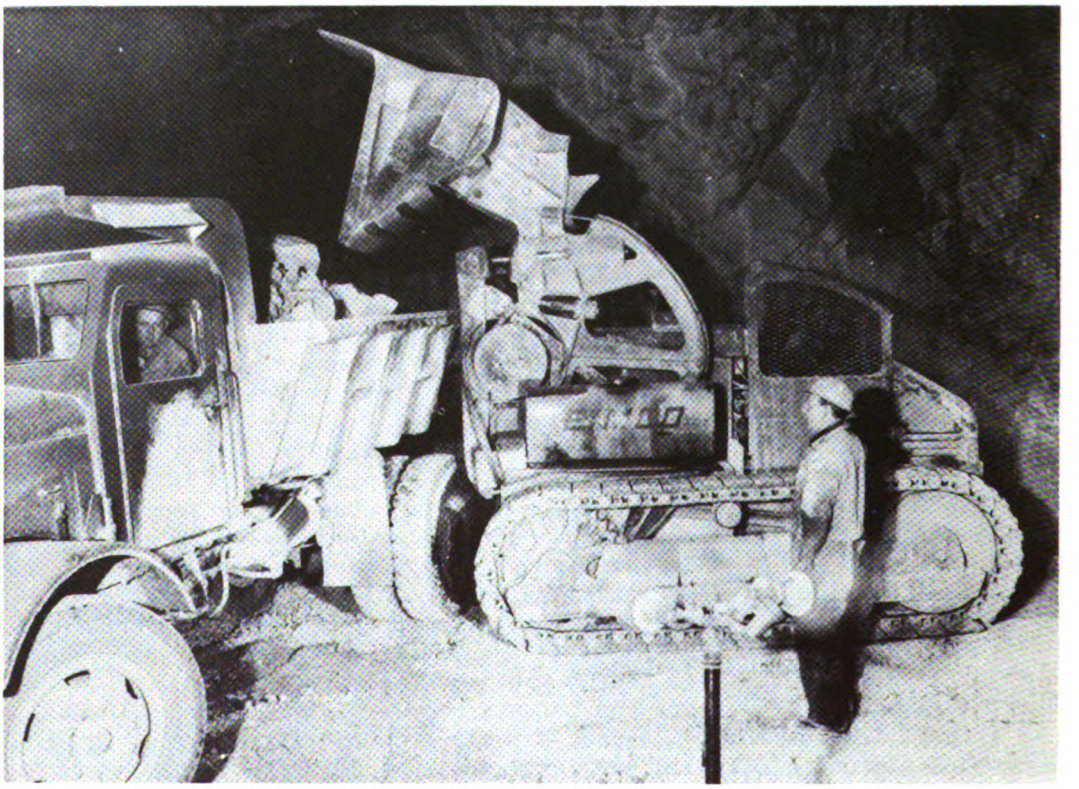

Figure 13. - Loading stone with overhead shovel.

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may be intersected is removed in the same manner. Skimming when necessary prevents dilution of waste material with the high-grade stone body of the pile. Before stone is loaded from a heading, the Eimco loader skims the floor and does the work of a bulldozer by pushing stone scattered by the blast to the main body of the broken stone at the face.

Trucks are loaded from the side (see fig. 13). The loading and haulage crew consists of an Eimco loader operator, a pitman, and truck drivers. The pitman directs the loading operation by hand signals, adjusts the lighting, and greases the Eimco loader. It is remarkable how expert the truck drivers become in backing trucks so that the side of the box, in one backward sweep of the truck, comes to rest within a few inches of the loaded shovel. The first shovelful of stone is always ready for dumping when the truck arrives. The time required by the shovel loader to pick up the 4 shovelfuls of stone (truck capacity) and dump is 1-1/2 minutes. The time required by the truck for a complete round trip, including loading and dumping, is 15 minutes. With 3 trucks in operation about 8 tons is delivered to the primary crusher every 5 minutes when no delays intervene. The time will be shortened when a larger primary crusher is installed. The length of road on the surface from the crusher to the entrance of the opencut leading to the mine portal is 375 feet. Upon arrival in the primary crusher area, the trucks turn and back to dump over a horizontal timber (oak)-floored ramp 16-1/2 feet wide by 45 feet long. A timber backstop places trucks in position for end-dumping the load into the crusher.

As previously mentioned, the 10-ton-capacity, Euclid, end-dump trucks are diesel-powered by 125-hp. GM motors. They are equipped with power steering. The truck-box sides are flared outward; this type of box is necessary for side loading (as the shovel bumper may strike the rim of the box before discharge of stone occurs) and prevents damage to any part of the vehicle. Trucks fully loaded negotiate road grades as steep as 22 percent without difficulty. A truck-maintenance schedule is strictly followed. They are greased every Friday afternoon, and oil is changed after every 100 hours of operation. Care is also taken in maintaining roadways free of broken stone spilled from trucks. Drivers stop and remove stones on return trips. Tires are thus worn out instead of blown out and have been found to last 2 years before recapping or replacement.

MINE ROOF AND ROOF BOLTING

The high-quality limestone is overlain by a bed of laminated, silty, dark-gray limestone 2 to 6 feet thick, with smooth but nubbly partings ranging from 1 inch to 6 inches in thickness. Near the contact with limestone and laminating stone tends to peel, and in the vicinity of any cave openings it is structurally weak. If not taken down it must be supported by some means, preferably by roof bolts. In parts of the mine the roof material is better cemented and has been peeled to a good roof. By the end of 1954, 830 bolts had been installed in the front of the mine, mostly on 5-foot centers but more closely spaced at random near boundaries where the bed is cut by caverns and exposed in cross section, thus breaking the continuation of a roof-beam support. As the mine extends deeper under the hill, the roof appears to strengthen, and there is less necessity for roof bolting. Rock bolts 3/4 inch in diameter, 4 to 6 feet long, have been used with the Pattin expansion shell and 3/8- by 6- by 6-inch baseplates. Holes were drilled by a light Ingersoll-Rand wagon drill with a 1-3/8-inch-diameter tungsten carbide bit on integral 1-inch hexagonal steel. Bolts were installed and tightened with a No. 554 Ingersoll-Rand impact wrench. More recent practice has been to use 5/8-inch-diameter bolts and tighten bolts with a torque wrench at 350 foot-pounds torque. Recommendation by the Roof Control Section of

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the Bureau of Mines[5/] reverses the trend of overtightening bolts beyond the elastic limit. As bolts follow the pattern of the steel stress-strain curve, tightening of 5/8-inch-diameter bolts beyond 130 foot-pounds for 1020-25-C bolts and 172 foot-pounds for 1040-45-C bolts merely tends to stretch and elongate the bolt and allows no safety factor for any added load on the bolt.

A major striated and slightly corrugated fault plane that cuts bedding at a slight angle is found in some of the more recent openings; in places it extends a few feet below the upper limit of the bed. Corrugations indicate that the fault movement has been N. 30° to 50° W. The fault nearly parallels the warp of the deposit and forms a good roof to mine against.

In places where the upper contact of the deposit is cut by caverns or seams that can be detected in advance, the floors of development headings are depressed to carry the roof of the tunnel several feet below the upper contact of the limestone bed.

A roof area in the "upper development heading" near the mine portal tends to flake and spall, particularly during the summer when the humidity is highest. This condition has been remedied by pinning 1,600 sq. ft. of punched steel plate (aircraft matting) to the roof. The mat (see fig. 14) is effectively and tightly held in place by 3/4-inch-diameter roof bolts 2 feet long spaced 2 feet apart in rows 2 to 5 feet apart. The mat was put up from a sectional-steel scaffold loaned from the plant.

The Jumbo can also be used for drilling vertical holes for roof bolts where the roof is beyond easy reach of the wagon drill, as the long drill carriages can be tilted into a vertical plane. After drilling, the drill carriages can be used to support a platform for workmen to install the bolts. A roof as high as 30 feet can be reached in this manner.

AUXILIARY FACILITIES; EQUIPMENT AND OPERATION

There are no shop facilities underground, except for a limited quantity of lubricating oil and grease neatly kept at a station in a crosscut for service maintenance of trucks, the Jumbo and Eimco loader.

Air Compression; Air and Water Lines

Compressed air for drilling is supplied by a Gardner-Denver, 21- by 13- by 14-foot, Model HAF, horizontal, duplex, 2-stage air compressor, displacement 1,545 c.f.m., housed in a building near the entrance to the opencut leading to the mine portal.

The compressor building 22 feet, 5 inches, by 25 feet, 0 inch, by 12 feet, 3 inches (inside dimensions) is of steel-frame, cinder-block construction. It has a concrete floor and flat wood roof. The 5-step-control, water-cooled compressor is powered by a 2,300-volt, 3-phase, 60-cycle, 250-hp, synchronous motor. The motor speed is 277 r.p.m., and the drive shaft is geared at both ends to the twin compressor unit. An auxiliary motor-generator set supplies direct current to the field

5/ Barry, A. J., Panek, L. A., McCormick, John A., Use of Torque Wrench to Determine Load in Roof Bolts, Part 3, Expansion-Type 5/8-Inch Bolts: Bureau of Mines Rept. of Investigations 5228, 1956, 13 pp.

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Figure 14. - Steel mat pinned to roof, protecting haulageway near portal.

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coils. Power is automatically disconnected when an excess of 40 amperes is drawn on the d.c. line and a motor load exceeding 56 amperes is taken on the a.c. side.

The compressor is fitted with an oil filter intake. Set to cut off at 100 p.s.i., the compressor delivers 95 p.s.i. at the drills, and the compressed air is both inner- and outer-cooled by water jackets. Moisture is thus condensed before air reaches the drills, resulting in a fogfree face during drilling. Water for cooling is pumped and recirculated through the cooling tower at the plant, and the flow is constant and not closed off when the compressor is stopped between shifts. In cold weather the compressor house is kept at even temperature by an electric strip heater.

Compressed air is delivered to a 140-cu. ft.-capacity vertical receiver outside the building and fed to the mine through a partly buried, 6-inch-diameter steel pipeline laid on the right side of the roadway facing the mine portal. At present the 6-inch line is 700 feet long and extends into the mine on the right side of the "upper development heading". Fittings are provided in the line opposite crosscuts for future compressed-air requirements in benching floors. These branch outlets are reduced to 4-inch-diameter pipe and equipped with gate valves for future extension. When compressed air is required for benching in the crosscuts, the 4-inch branch-lines are carried across haulageways under the roadbed.

At 700 feet the 6-inch-diameter pipe or main header is reduced to 4-inch diameter, and the 500 feet of this latter-size pipe, joined by Victaulic couplings, is carried ahead in the vicinity of the active development headings. When the 4-inch line is moved ahead, more 6-inch pipe is added. The 4-inch line may extend 200 feet beyond the end of the 6-inch-diameter pipe along the upper development heading and then be turned under the roadway to be carried under or along the floor on the right side (facing in) of the last completed crosscut. Convenient outlets are provided in this pipe for hose connections.

The Jumbo is fitted with 300 feet of 2-inch, 3-ply, rubber-covered air hose (150 p.s.i. test) joined in 50-foot sections by Boss Screw couplings and 300 feet of 1/2-inch, 3-ply, rubber-covered water hose (200 p.s.i. test), which are connected to the nearest pair of pipe outlets. When the distance between the active headings and the nearest pipe outlets approaches 300 feet (maximum length of hose) the pipelines are extended.

Raw water for drilling, pumped from the plant at 80 p.s.i., is carried to the mine portal at 1-1/2-inch-diameter pipe. The pipeline is then reduced to 1-inch diameter for extension into the mine, paralleling the compressed-air line. Both air and water lines terminate at the same place.

Ventilation and Air Conditioning

Mining laws of the State of Virginia permit the use of diesel-powered equipment in underground limestone mines at the discretion of the State mine inspector. The Sunbright mine is mechanically ventilated by an exhaust fan described in the chapter under Equipment. The fan is on surface at the top of a 6- by 8-foot, vertical raise 120 feet high that was driven from the south center mine area. On the surface the raise is enclosed by a 9- by 10-1/2- by 7-1/2-foot box built of cinder block on a concrete-slab foundation. The roof is of prefabricated concrete-slab construction, sealed and covered with bituminous cement and rock chips. It is supported at the center by a steel beam embedded in the cinder block walls. A small wooden doorway (2 feet, 6 inches, by 3 feet, 4 inches) on the side of the housing, facing the gate

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of the enclosing fence, provides access to the top of the raise (see fig. 15, arrow). The door opens to a steel-grate floor platform (4 feet by 4 feet, 6 inches) that covers a part of the open ventilation raise nearest the fan intake. The platform is supported on steel beams and guarded by a handrail. Access is thus provided to the 4-foot, 5-7/8-inch-diameter, side-intake tubing, which is part of the fan housing. The fan exhausts vertically through the circular fan housing (4 feet diameter) and is belt-driven (5 V-belts) by a dustproof, induction, squirrel-cage motor, rated 100 hp. (but horsepower reduced), 440 volts, 3-phase, 1,185 r.p.m. The fan is not speeded to rated capacity. Greater output can be obtained at will by adjustment in the ratio of pulley diameters. The present exhaust is sufficient for ventilating the mine. Power is supplied from a bank of three 3-phase, oil-filled transformers (30 kv.-a. each) mounted on an overhead platform between 2 poles. The transformers reduce incoming current from 2,300 volts to 480, purposely set to permit a line drop to 440 volts. A transformer built into the starter box reduces the voltage from 440 to 110 for controlling the motor starter. One push-button starter is on the surface near the motor and another at a point in the mine near the air intake of the ventilation raise. The 110-volt extension line from the starter on the surface is enclosed in a conduit extending down through the raise. The fan installation and motor on the surface are enclosed by a fence, and the gate is kept locked.

The dimensions of the air intake at the start of the raise are 8 by 9 feet, due to overbreak. The unlined walls are relatively smooth. Velocity readings were taken with an anemometer fastened to a pole made by splicing two blasting sticks together. Five readings were taken over periods of 3 minutes each, 1 at each corner about 18 inches from the walls and 1 at the center of the raise. The anemometer was held about 20 feet above the crosscut floor, which is 2 feet above the roof of the crosscut. The average of 5 readings indicates a velocity of 630 f.p.m., which, when applied to the area, approximates a discharge by the fan of 45,000 c.f.m.

Velocity readings taken with the anemometer at the mine portal were inconsistent. No movement of air was noted at the top of the portal; and the air flow breast high and along the floor came in gusts, with velocities about 120 f.p.m. The flow of air is more noticeable in the interior of the mine. It is quite possible that some air is taken in from caverns. The supply of fresh air in the mine is excellent. The velocity flowing through the airways is sufficient to carry away dust and fumes without stirring up dust from roadways.

Air is drawn to the mine workings through the upper development heading and the most distant completed crosscut from the mine portal. To prevent short circuiting, other completed crosscuts are closed off by brattices (see fig. 16) constructed of a framework of 1-inch-thick boards (rough-sawed oak) and brattice cloth. The brattices are braced with 2- by 4-inch scantling or any other size posts available. As a rule, hinged double doorways (each door 5 feet, 5-3/4-inches wide by 11 feet high) are built in the brattices for passage of trucks to and from benching operations. Doors are kept open when mucking is in progress, and all doors are opened when blasting takes place to prevent the collapse of brattices. The brattice cloth, unlike a solid wall, allows some eleasticity to air movement when subjected to sudden pressure.

No records of temperature and humidity are kept. Readings taken with a sling psychrometer on January 18, 1956, were: Temperature at portal, 44° F.; relative humidity, 36 percent. Inside the mine at the beginning of the return aircourse in the far end of mine: Temperature, 48° F.; relative humidity, 60 percent. With a rise of only 4° F. in temperature, the humidity had nearly doubled.

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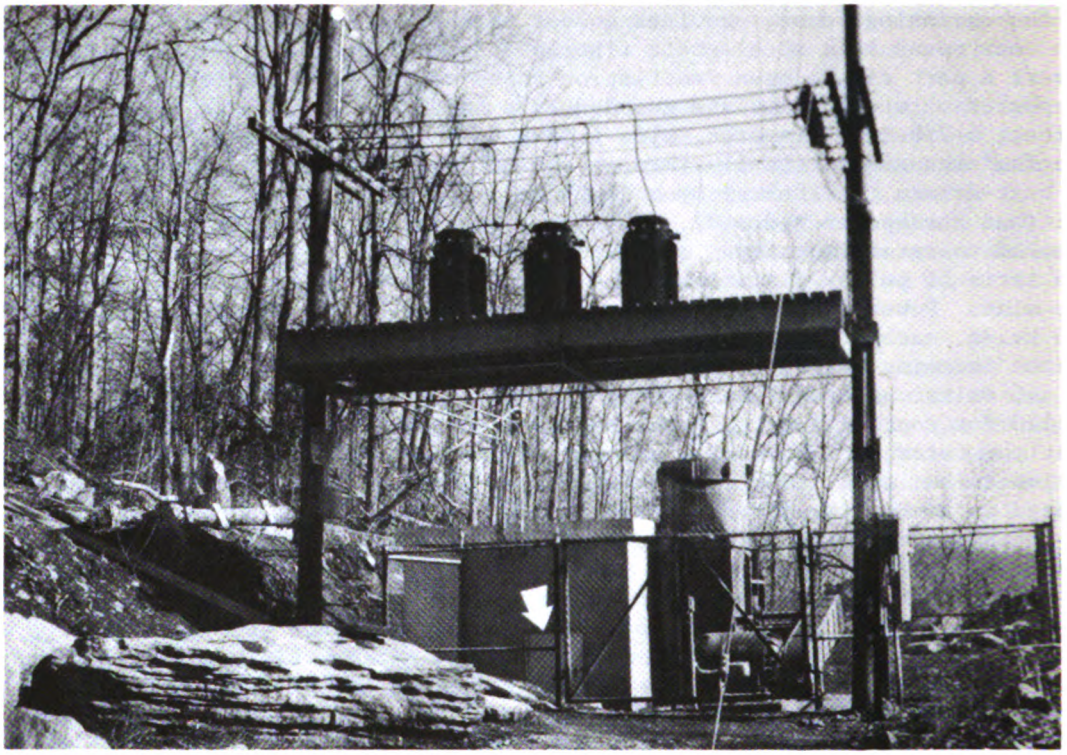

Figure 15. - Mine-ventilation system; surface exhaust fan.

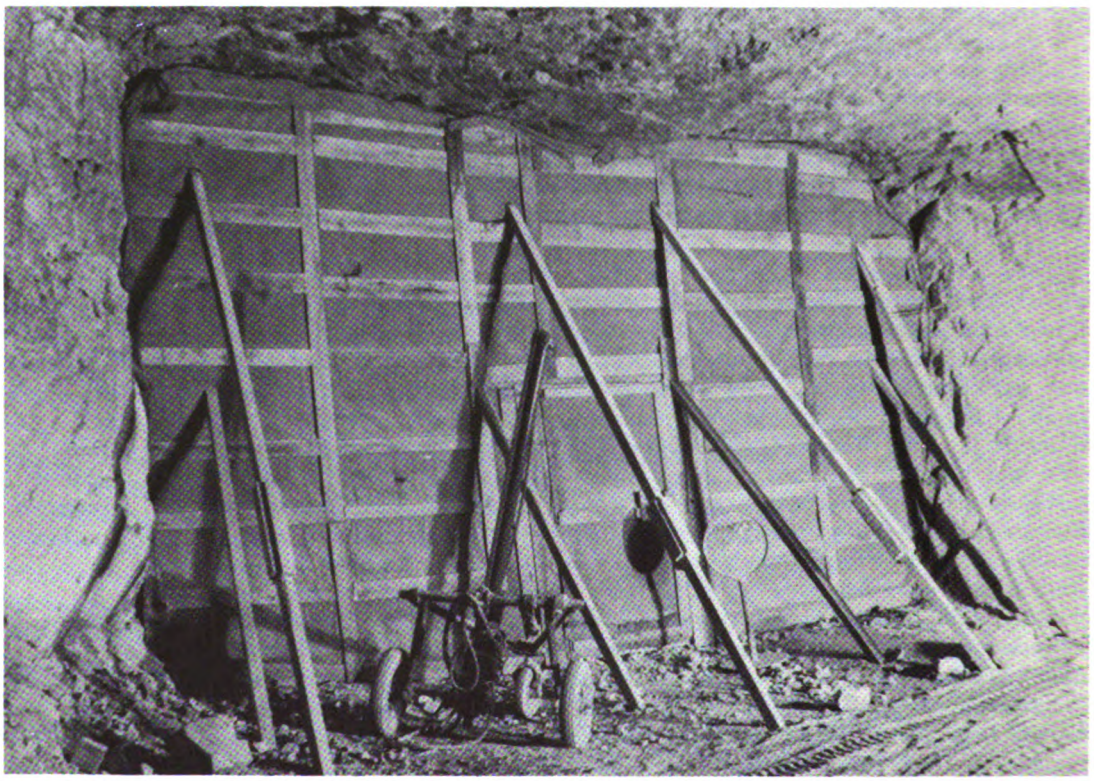

Figure 16. - Brattice closing a crosscut in "upper development heading;" single-door entrance.

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Temperature and relative humidity readings taken are shown on the ventilation diagram (see fig. 17).

Underground Lighting and Telephones

Mine production is concentrated in 2 areas, 1 at the end of the mine where development headings, crosscuts, and pillar breakthroughs are advancing and the other closer to the portal, where benching of floors is in progress. It is only in these areas and along the main haulageway that lighting is required. Electric power for lighting enters the mine at 440 volts a.c. from a bank of transformers on the surface near the ventilation-fan installation. The power cable, enclosed in a conduit, is taken down through the vertical ventilation raise to a 25-kv.-a. transformer near the air intake, where current is stepped down to 110 volts. A waterproof string of light cable is then carried underground to the mine portal and extended into the mine, following the compressed-air line to terminate near the end of the pipelines. The wires are carried on steel brackets from the tunnel wall 3 to 4 feet above the floor. Receptacles are provided for 150-watt frosted bulbs, which ordinarily are spaced 40 feet apart to the end of the lightline. Clusters of 3 to 4 GE, 150-watt, 120-volt, self-contained, floodlight bulbs, mounted on portable, pipe-stand tripods, are used for lighting tunnel headings. Extension cords 200 to 300 feet long (2-conductor, No. 12, rubber-covered, industrial-type wire) are plugged into the lighting circuit. The pipe tripods (see fig. 13) are fitted with metal, Stonoco, adjustable-socket receptacles for receiving the bulbs. These portable floodlights are very durable and provide excellent illumination for scaling, installing roof bolts, loading tunnel headings with explosive, and loading trucks with stone. The benching area is similarly illuminated. A tripod is set 30 feet back from faces being loaded with explosive, and other tripods are placed where most convenient for other phases of mining.

The Jumbo is fitted with three clusters of 150-watt, self-contained, floodlight bulbs, and the lighting system is also served by 300 feet of 2-conductor, No. 12, rubber-covered, industrial-type wire, with plug-in extension cord.

No caplamps or handlamps are carried in the mine. Two small carbide lamps are stored in the underground lunchroom for emergency use or for use of the engineer in making surveys.

Headlamps on Euclid trucks are "on" at all times trucks are in motion, and each truck is fitted with an auxiliary "backup" light.

Two lead wires from the lighting circuit at the portal are extended to a point near the compressor house. In case of power failure, these wires are spliced to a portable, gasoline-powered generator available by rent from a local contractor. At such a period, which happens only occasionally, the mine crew can work at scaling or at completing miscellaneous odd jobs in the mine.

All electric lines, including light and telephone wires, together with pipelines, are kept on the right side of the upper development heading and on the right side of crosscuts. The left side of these openings is reserved for installation of permanent wiring for a blasting line when it becomes desirable to do all the shot firing from a point near the portal or outside of the mine.

A telephone line is carried into the mine through the portal, and 2 telephones are installed underground, 1 near the site of benching and the other at the end of the compressed-air pipe near the present underground lunchroom. The phones are

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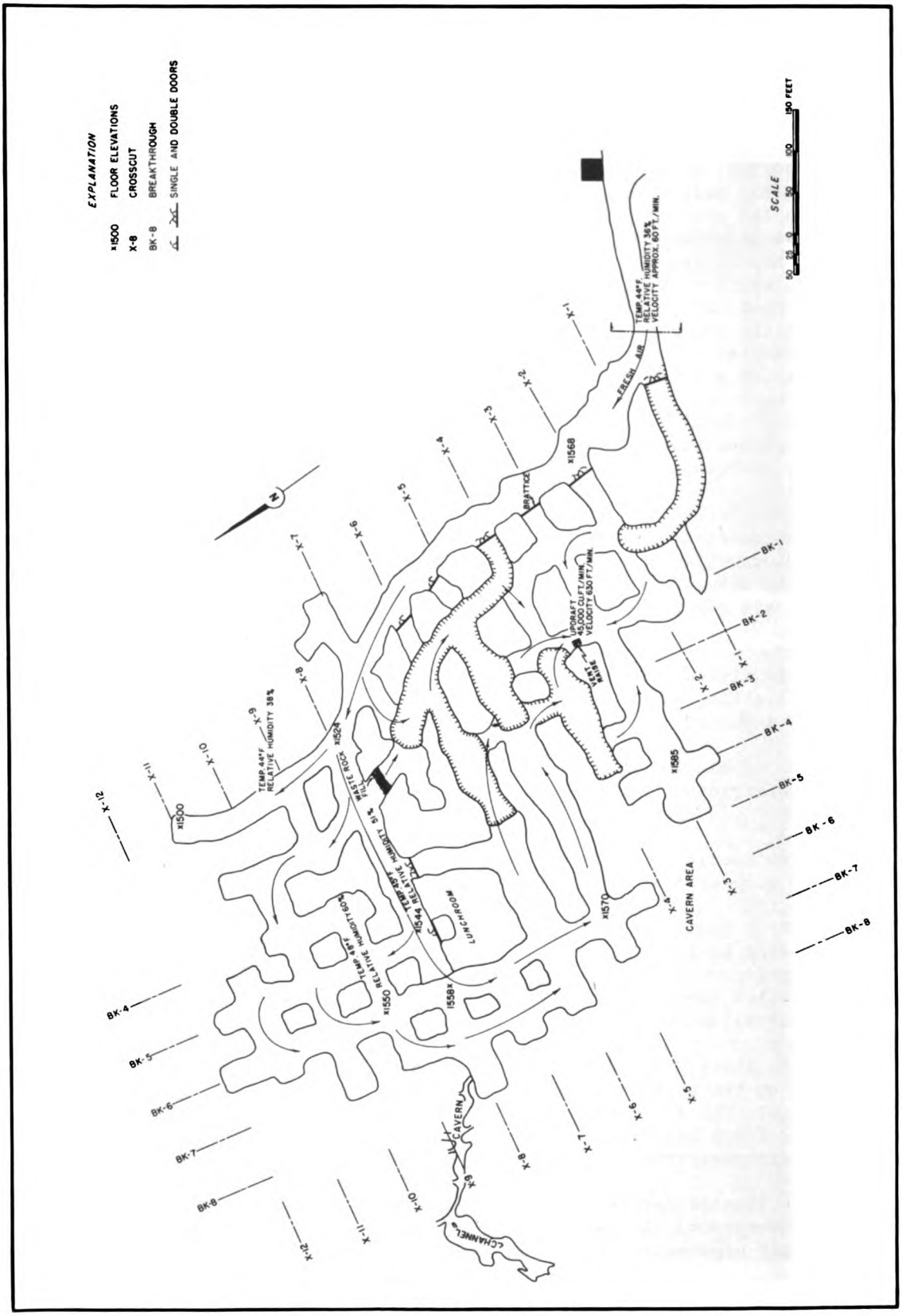

Figure 17. - Ventilation diagram, Sunbright mine, readings taken January 18, 1956.

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connected to the plant switchboard, and the switchboard operator also controls a separate, automatic, horn-sounding locator system that is interconnected with various other outside phones in the plant. Each supervisor is assigned a special call signal, such as 1 long and 2 short blasts of the horn, repeated until the person wanted is reached anywhere within the working area of the mine or plant. The 110-volt cable for the call system, boosted by relays to maintain voltage from handy sources on the surface, is carried into the mine through the portal.

Office phones are serviced from the switchboard by the conventional bell ring.

Details of Magazine Construction and Storage of Explosives

No explosives are stored underground. "Powder" is transported in original cases from the surface magazine daily as needed. Detonators are carried in a box especially built with compartments for various millisecond delays. Both the powder magazine and the "cap" magazine, which are 140 feet apart, were built to service the original quarrying operation. The powder magazine is nearest to the mine, 140 feet west of the entrance to the opencut leading to the portal. It is constructed of cinder blocks and roofed with a 6-inch-thick, poured-concrete slab, with openings for two 10-inch-diameter ventilators. Inside dimensions are 7-1/2 by 13-1/2 by 7-1/2 feet. The floor (21 inches above ground) is of wood 2 inches thick, with holes bored through it, 1 inch in diameter, for ventilation. Inside walls, spaced 1-1/2 inches from the cinder block are of wood latticework for complete ventilation. A 3- by 6-foot steel door is wood-lined. The magazine has a capacity of 20,000 pounds of explosive which is delivered by truck in 10,000-pound lots. To prevent the accumulation and aging of explosive, storage is withdrawn from the magazine one side at a time. When 1 side of the magazine is empty, another 10,000 pounds of explosive is ordered. The new shipment is stored until all of the powder in the opposite side of the magazine is used. The average withdrawal of explosive from the magazine per working day is 450 pounds.

The "cap" magazine is likewise made of cinder block, but the roof is constructed of prefabricated concrete slabs. Inside dimensions are 8 by 10 by 6 feet. The 2-inch-thick wood floor is 2-1/2 feet above ground. The 3- by 6-foot steel door is wood-lined inside. Shelving is built along the wall opposite the door and at both ends of the building. The magazine has storage for 12,000 detonators, but only about 4,000 are kept in stock from No. 0 to 225 millisecond delays, as they can be obtained on a 4-hour service schedule from the Du Pont storage magazine at Norton, Va., 30 miles away by highway. Only one make of detonator is purchased, which avoids any possibility of misfires due to mixing brands.

The magazines appear at the right in figure 18.

CRUSHING

Trucks hauling crude limestone from the mine to the crushing plant (see fig. 18) are backed over the timber (6- by 8-inch oak) floor ramp to dump onto a belt-driven (8 - "V"-belts), 20-inch, Telsmith, gyratory crusher powered by a 440-volt, 100-hp. dust-proof, squirrel-cage, induction motor. Both crusher and motor are supported on concrete foundations. The crushed stone (minus-5-inch diameter) drops and is fed through a steel chute to No. 1 rubber, 4-ply belt conveyor (1/2 by 30 inches). The sides of the chute are rubber skirted to prevent spillage. The conveyor, inclined at 18°, is 97 feet long and is operated at 210 f.p.m. It is powered by a 15-hp., Link-Belt, chain-drive electric motor and elevates the material from the primary crusher to the top of the secondary crusher building, where the discharge from the

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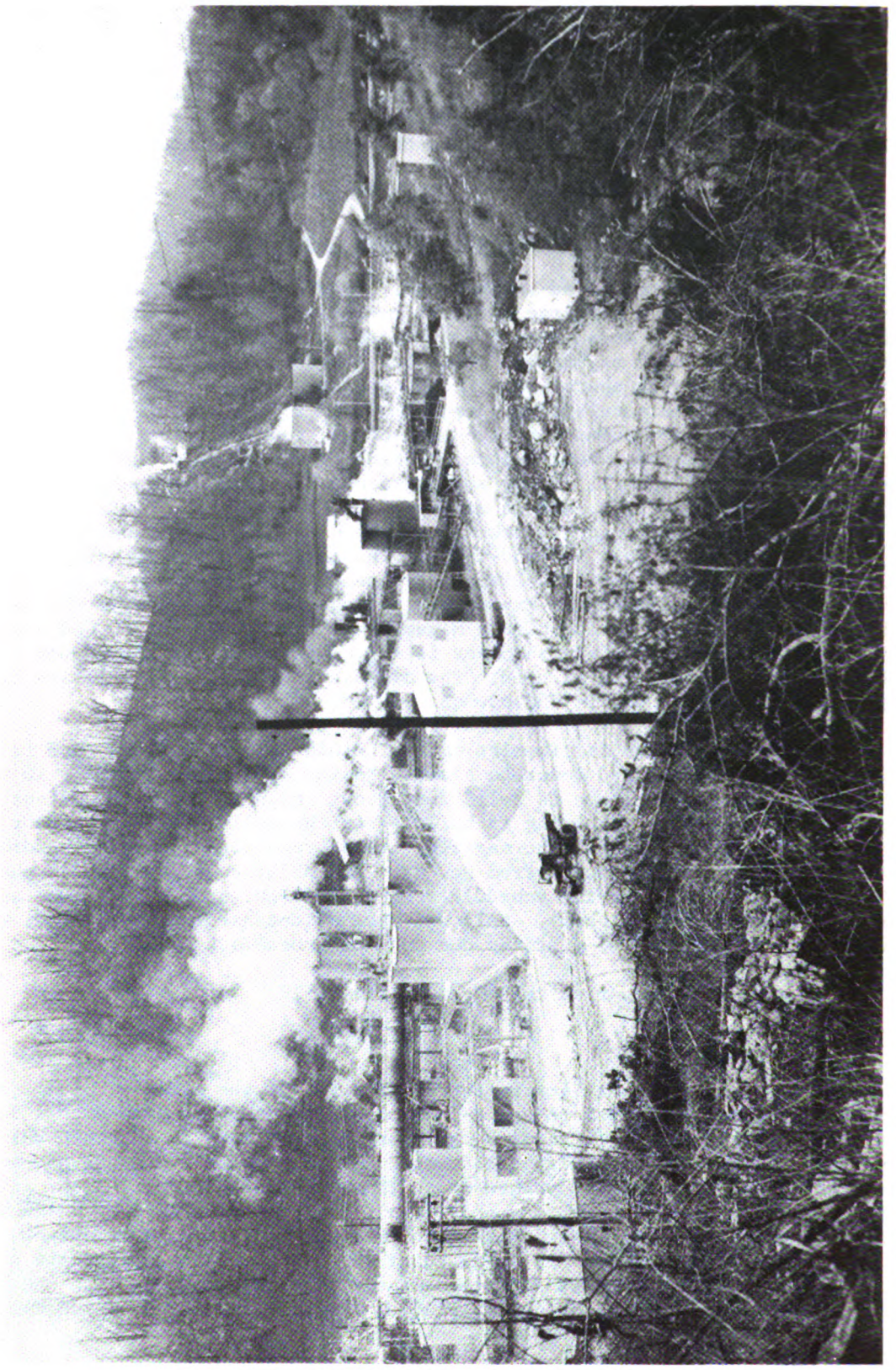

Figure 18. - View of crushing plant from vicinity above mine portal. Powder and cap magazines to right.

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belt in falling is split by steel wedge and spread over a 4- by 12-foot, 2-deck, Ty-Rock, vibrating-screen, multiple belt driven by a 10-hp., 440-volt motor.

The top screen has 2- by 2-inch openings, and the bottom screen openings are 3/8 by 3/8 inch. Waste product dropping through the screens, containing dust contaminated by silt from the mine, falls to a storage hopper and is removed by truck for surfacing plant roads or hauled to the waste dump.

Oversize from both screens is dropped through a steel chute with a sloping upper section and a vertical lower section completely enclosed (12 by 48 inches cross section), leading to the top of a size CF-11-44, Pennsylvania, Steelbuilt, reversible-type impactor. This hammermill, containing 3 rows of beaters (5 beaters per row) has a speed of 900 r.p.m. It is driven through a flexible coupling powered by a 2,300-volt, 870-r.p.m., 250-hp., totally enclosed, Allis Chalmers, fan-cooled, dustproof, squirrel-cage, induction motor. Discharge from the impactor hammermill (stone broken to minus-1-inch diameter) feeds directly to the No. 2 (4-ply conveyor belt, 3/8 by 30 inches). This conveyor, 119 feet long, also driven at a speed of 210 f.p.m. by a 440-volt, 15-hp., dustproof motor, elevates the crushed stone at an inclination of 18 degrees and discharges on No. 3 cross-stacking conveyor. The crushed product is thus further elevated at an angle of 18° on a 4-ply 3/8- by 30-inch conveyor belt to a height of 40 feet above ground and discharged, falling freely to storage. No. 3 conveyor belt, centrally driven, is 148 feet long and travels at a speed of 260 f.p.m. It is powered by a 440-volt, 5-hp., dustproof, quirrel-cage, induction motor.

A cyclone dust-collector system, originally designed and installed for a secondary crushing-plant capacity of 500 net tons per day, is sufficient for the present increased production. The collector system consists essentially of a Sturtevant No. 60 planing-mill exhauster that draws dust through ducts from the Ty-Rock screen and from the impact crusher to a pair of cyclones. The exhauster is belt-driven by a 440-volt, 30 hp., dustproof, squirrel-cage, induction motor. Dust is discharged from the cyclones to a hopper. The dust is drawn from the hopper through a blast gate for discharge to trucks.

Other specifications of this unit are:

Dust	40 - 50 NT per day
Particle size	50-mesh down
Carry velocity	6,200 ft. per min.
Air handled	6,600 c.f.m.
Storage capacity	50 NT

When coned to the height of the stacker-belt conveyor (fig. 19) the storage pile contains 8,000 tons of crushed limestone.6/ Plant feed is drawn through an opening in the roof of a tunnel at the center base of the pile and transported by belt conveyor to a ball mill, where it is wet-ground to further size reduction.

The primary crusher motor and No. 1 conveyor-belt motor are started or stopped by push-button controls at the operator's station above and back of the crusher where the operator is on constant duty at the truck dumpsite. Push-button controls of secondary units in the crushing plant are installed in the building housing the shaking screen and secondary (impact) crusher. All units except the primary crusher are in constant operation during the shift. The primary crusher is stopped during

6/ The angle of repose has been measured at 39° from the horizontal.

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Figure 19. - View from primary crusher showing end of stacker conveyor discharging crushed stone to stockpile.

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the lunch period or whenever there is an intermission in truck delivery of stone from the mine. The crushing plant is operated by two men, a crusher operator and a helper.

About 12 percent of the mine production is discarded as fines, and 6 percent is sorted and discarded at the mine. It is anticipated that the better roof conditions being encountered as the mine extends deeper under cover will result in less waste discard in the mine and better recovery at the screens. Some of the waste material under 3/8-inch diameter from the vibrating screen is used for surfacing roads in the mine and around the plant, but most of it (plus waste rock from the mine) is hauled to the plant site and dumped for fill in leveling additional ground to the plant elevation.

Total mine production for the 6-month period commencing July 1, 1955, was 102,117 tons, averaging 39.4 tons per man-shift underground. Crushing per man-shift based on tons mined was 189. These production data include the 18 percent of tonnage discarded in the mine as waste and the fines removed by the Ty-Rock screen.

SUMMARY TOTAL OF EQUIPMENT, POWER, AND SUPPLIES

Mine equipment, aside from the surface crushing unit, consists of the following items:

Underground Quantity	Description
1	JSP Gardner-Denver, mobile, self-propelled, 2-boom Jumbo, complete with 2 Gardner-Denver 3-1/2 inch (piston dia.), type D93D, percussion drills. Chuck for 1-1/4-in. round, lug steel.
2	Worthington UM 40 wagon drills, complete with carriage slides for 8-foot steel change and 3-1/2-in. (piston diameter), percussion drills. Chucks for 1-1/4-in.-diameter, round, lugged steel.
1	Ingersoll-Rand light wagon drill, complete with carriage slide for 6-foot steel change and 2-1/2-in. (piston diameter), DA 30, percussion drill. Chuck diameter, for 1-in. hexagonal steel.
1	Jackhammer, Ingersoll-Rand. Chuck for 1-in. hexagonal steel.
1	Eimco Rocker Dump (overhead) shovel, Model 104, on caterpillar-tractor chassis, diesel motor, 48 hp., 4-cylinder. Shovel capacity, 1-1/4 yd. Size of bucket as measured, 5 ft.,6 in. wide, 3 ft., 9 in. high, 2 ft., 9 in. deep. Wt. of machine, 24,000 lb. Headroom required to swing bucket, 13 ft., 6 in.
1	Eimco rocker-dump (overhead) shovel, Model 105, diesel motor, 90 hp., 3-cylinder, 2 cycle. Shovel capacity, 1-1/2 yd. Size of bucket as measured, 5 ft., 6 in. wide, 3 ft., 10 in. high, and 4 ft., 7 in. deep. Wt. of machine, 38,500 lb. Headroom required to swing bucket, 15 ft., 6 in.
3	Euclid trucks, 10-ton-capacity end-dump, power steering. Trucks are diesel-powered, with 125-hp. GM motors. Box sides are flared. Top of box, 7 ft. from ground level.

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Underground (Con.)	Description
Quantity (Con.)	
1	Permissible dust collector for sampling, complete with 20 ft. of 2-in.-diameter suction hose and 26 ft. of 1/2-in.-diameter, air hose. Mfgr., United Engineers, Inc., Brimingham, Ala.
8	Portable (shop-made) pipe-constructed tripods 3-1/2 ft. high, equipped with 3 - 5 Stonoco, adjustable metal-socket receptacles in clusters for 150-watt floodlamps. Stands are equipped with 200- to 300 ft. of 2-conductor, No. 12, rubber-covered, industrial wires with plugs.
1	Portable Du Pont condenser blasting machine, complete with light metal reel containing 200 - 300 ft. of standard rubber-covered blasting cable.
1	Transformer, 25 kv.-a., 440/110 volts.
10	Aluminum tube (1-1/4 in. O.D. - 1 in. I.D.) scaling bars fitted at 1 end with steel gads, flat, curved points. Bars range in length from 8 - 20 feet.
4	Magnesium-metal extension ladders in 2 sections, each 10 ft. long.
3	Round-point, long-handled shovels.
1	Box of assorted tools.
2	Telephones, with accessory 110-volt, horn-sounding, locater system.
Surface	
1	Gardner-Denver, Model HAF, 21 by 13 x 14 horizontal duplex, 2-stage, 5-step-control, water-cooled air compressor, capacity 1,545 c.f.m. displacement, powered by a.c., 2,300-volt, 277 r.p.m., 250-hp., GE synchronous motor.
1	Mine ventilation fan (originally purchased as a flue-gas exhaust fan). New York Blower Corp., type ME fan, No. 490, Arr. 8 (fig. 5), class IV. Rotor: 3/16-in. steel plate; inlet damper for automatic control. Clockwise rotation, side inlet 53 7/8-in. I.D., up exhaust, 4 ft., 0 in. diameter. Rated capacity 53,000 c.f.m. at 1,780 r.p.m. Fan is powered: V-belt drive, identical pulleys, by GE dustproof 100-hp., 3-phase, 60-cycle, 440-volt, 1,185-r.p.m., squirrel-cage, induction motor, complete with push-button control.
1	Bank of 3 three-phase, oil-filled transformers, 30 kv.-a., 2,300/440 volts.
1	Fuel pump, electric, complete with buried steel tank, capacity 1,000 gal. diesel fuel.
1	House trailer for mine office, complete with telephone, chair, filing cabinet, first-aid equipment, and supplies.

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Power is supplied to the plant by the Appalachian Power Co. from the Lovedale substation, Kingsport, Tenn., 20 miles cross country southeast of Sunbright. It enters the plant at 33,000 volts and is stepped down to 2,300 volts and 440 volts for primary and secondary distribution, respectively. In general, all motors over 100 hp. are on 2,300 volts. A feeder line distributes 2,300 volts to the mine (see electric power diagram, fig. 20), where, for operation of the ventilation fan, it is further reduced to 440 volts by a bank of three 30-kv.-a. transformers. For lighting, a 440-volt lead in a conduit from these transformers extends down through the ventilation raise to a 25-kv.-a. transformer, where the voltage is reduced further to 110.

The crushing plant is supplied by electric power in voltage ranging 2,300, 440, and 110 from plant transformers.

Electric power to the mine and the crushing plant is not metered. The charge for power is estimated and based on the motor horsepower required to operate equipment and the number of hours of operation each month.

Average estimate for 1 month's operation follows:

	Power consumed, kw.-hr.
Air compression	36,400
Fan (ventilation)	8,400
Lighting	1,800
Crushing	70,000
Total	116,600

Consumption of the principal expendable items are listed as follows:

Item	Consumption, avg. per month
Drill bits	200
Drill steel ft.	200
Explosives lb.	7,500
Detonators	3,800
Diesel fuel gal.	950
Electric flood-lamp bulbs, 150-watt	24
Electric-lamp bulbs, frosted glass, 150-watt	12
Oil for trucks and loaders gal.	38
Oil for rock drills: Tonna "F" Shell do.	40
Grease lb.	15

EXTRACTION AND PRODUCTION RATES

A study of the mine map (see fig. 6) indicates that 70 percent of the area mined to date has been extracted and 30 percent of the stone has been left in place as pillars for mine roof support. Extraction has been increased to 80 percent at the north end of the mine because of better roof conditions.

Some dilution of limestone by waste is unavoidable, as the nearly vertical solution cavities or open seams and the larger caverns contain red clay or silt. Waste rock from overbreak (caused by peeling of weak, thin-bedded, silty limestone

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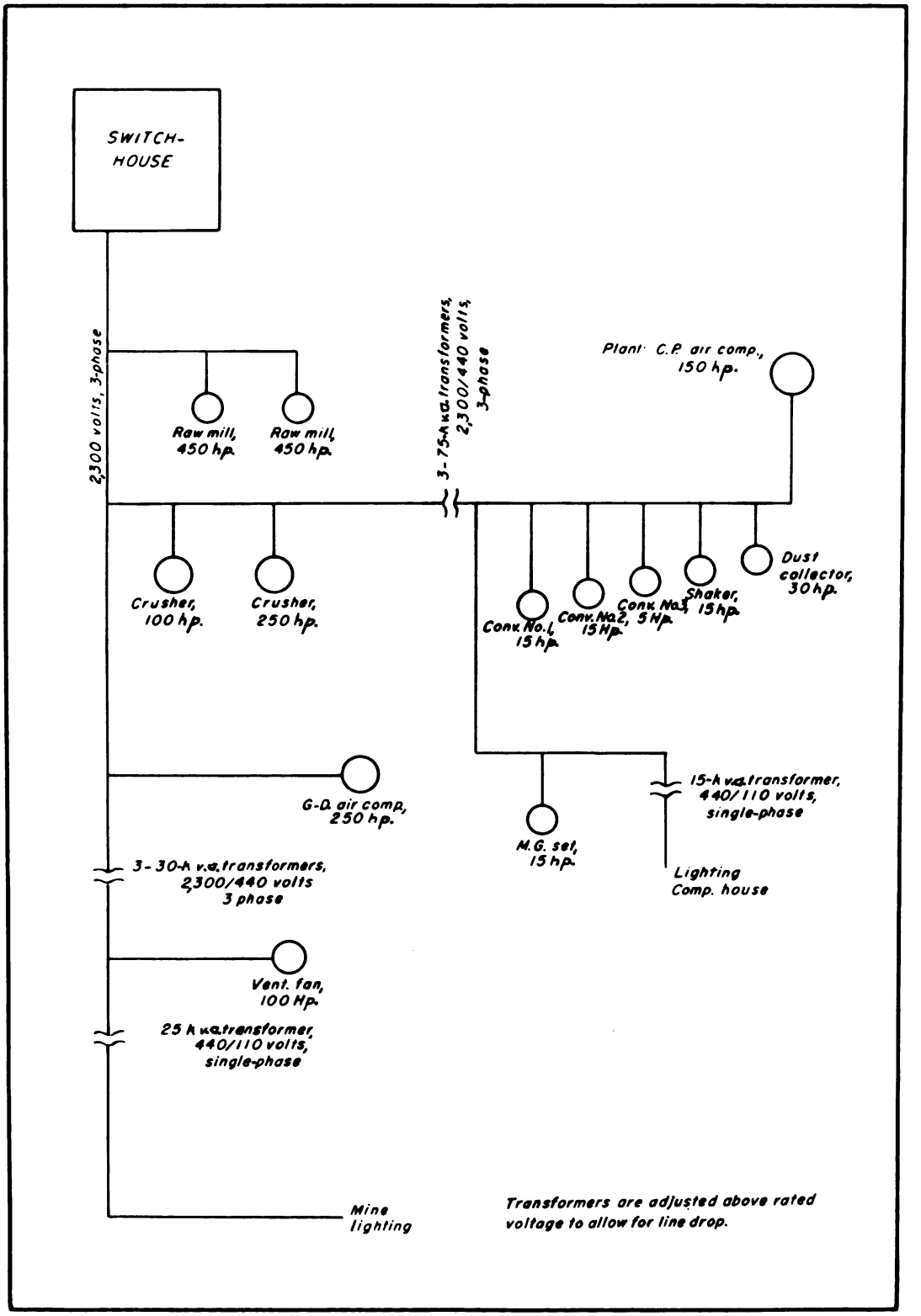
SWITCH-HOUSE
2300 volts, 3-phase
Raw mill, 450 hp.
Raw mill, 450 hp.
3-75-k.v.a. transformers, 2,300/440 volts, 3-phase
Plant C.P. air comp., 150 hp.
Crusher, 100 hp.
Crusher, 250 hp.
Conv. No. 1, 15 hp.
Conv. No. 2, 15 Hp.
Conv. No. 3, 5 Hp.
Shaker, 15 hp.
Dust collector, 30 hp.
G-D. air comp., 250 hp.
M.G. set, 15 hp.
15-k.v.a. transformer, 440/110 volts, single-phase
Lighting Comp. house
3-30-k.v.a. transformers, 2,300/440 volts 3 phase
Vent. fan, 100 Hp.
25 k.v.a. transformer, 440/110 volts, single-phase
Mine lighting
Transformers are adjusted above rated voltage to allow for line drop.

Figure 20. - Wiring diagram, switchhouse to mine.

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from the roof in blasting) is generally found on top of the broken stone pile. Scaling of the roof after blasting also accounts for waste material on top of the pile. It is readily identifiable by its dark color and lack of crystalline calcite. Such material is sorted in the mine and skimmed by the Eimco loader from the top of sloping muckpiles. All waste recovered is removed from the mine to the surface dump by Euclid trucks. Mud balls and waste stone are also hand-picked and discarded at the primary crusher when this material can be safely reached while the crusher is in operation. Fine silt, when found sprinkled in the ore, is trapped with the fines under 3/8-inch diameter and discarded on the shaker screen.

The mine is highly flexible as regards limestone production. The present output (averaging about 770 tons per working day) can readily be doubled by adding a permanent second shift and providing additional standby mining equipment to eliminate possible delays that may occur in case of mechanical failure.

LABOR

Both plant and mine are operated under security measures. Prospective employees, both labor and supervisory, are carefully screened before hiring.

No contract system is in effect. The Foote Mineral Co. has adopted a policy on a plantwide basis of distributing a bonus to employees, based on company earnings; at present this is paid half in cash and half in stock every 6 months.

The mine was started by recruiting and training local labor, but some employees of the mine travel to work from as far as Kingsport, Tenn., 26 miles by automobile. Labor and management relations are on a very high level. There is a mutual feeling of respect and friendliness between employees and supervisors that accounts for no labor turnover at the mine in the 2-1/2 years of underground mining. Wage rates are comparable if not higher than standard wage rates paid in the area.

Good results are obtained by planning the work and operating under close supervision with fixed standards of accomplishment.

The mine is scheduled for operation 1 shift a day, 5 days a week. To meet increased demand, a second shift has been temporarily added for loading, hauling, and crushing stone until a larger crusher is installed, as no provision is made for storing stone between the mine and the primary crusher without rehandling. The day shift, commencing at 8:00 a.m. and ending at 4:30 p.m., includes one half hour for lunch. The second shift commences at 4:30 p.m. and continues until 1:00 a.m.

The personnel employed on each shift is listed as follows:

Day shift No. of men	Payroll classification	Afternoon shift
1 driller (Jumbo	Same	1 Eimco loader operator
2 driller's helper (Jumbo)	do.	3 truck drivers
3 blaster	do.	2 crushermen
		6 Total
2 Eimco loader operator	do.	Loader operator is in charge of crew - second shift.
3 truck drivers	do.	
1 pitman	Driller's helper	
2 wagon drillers - samplers	Same	
1 crusher operator	do.	
1 crusher-operator helper	do.	
16 Total		

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Salaried personnel includes 1 mine superintendent, 1 mine foreman, and 1 mining engineer.

Wage Rates

Classification	Rate per hour
Eimco loader operator	$1.96
Driller (Jumbo)	1.63
Driller's helper (Jumbo)	1.46
Blaster	1.53
Driller wagon drill	1.53
Driller's helper, Wagon Drill ..	1.41
Euclid truck driver	1.60
Crusher operator	1.63
Crusher operator's helper	1.41

FIRE PREVENTION

There are no flammable materials underground that are remote from main haulageways, which are traversed constantly by trucks. Pyrene fire extinguishers are carried on all trucks, as well as on the Eimco loaders, and all mine personnel is instructed in their use. A portable carbon dioxide fog extinguisher is on order. When received it will be stored for emergency use in the compressor house on the surface.

Two dry-chemical, portable fire extinguishers are provided for use on electric fires, one each on the wall of the air-compressor house and on the wall in the secondary crusher building.

SAFETY METHODS AND FIRST AID

Accident prevention has been a major point of consideration since the mine was begun. All employees, both underground and on surface, have been instructed in safety and safe practices in connection with their respective jobs. Five qualified mine personnel have first-aid-training certificates issued by the Federal Bureau of Mines.

A check-in, checkout system, as required by the Virginia mining law, is adhered to, with a board and brass tags on a post at the mine portal. The board contains 2 tags for each employee, 1 of which is hung on the "in" side of the board and the other carried in the employees pocket when on duty in the mine.

Scaling is an important function in this mine, and all of the underground personnel, regardless of regularly assigned duties, is trained in safe, proper handling of the scaling bar. Blasters, Eimco loader operators, truck drivers, wagon drillers - all under supervision of the mine foreman - may do some scaling during the day shift. About 90 percent of all scaling is done after blasting from the broken stone piles. Before the last load of stone is removed from a heading, the face of the tunnel is completely scaled by the stone loading and hauling crew and prepared for the drilling. Scaling during the second shift is done by truck drivers and the Eimco shovel operator, who also acts as night foreman.

Scaling bars are made from aluminum tubing 1-1/4 inch O.D. and 1 inch I.D., in lengths as required - 8, 10, 12, 14 feet, or longer up to 20 feet. Chisel-pointed

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steel gads slightly under 1 inch in shank diameter are inserted tightly into one end of the tubing and secured by a 1/4-inch-diameter rivet.

A constant program of preventive maintenance is practiced by operators of mechanical equipment. Defective or worn unsafe parts are immediately replaced when found. This results in very little time loss due to mechanical failure and promotes safe operation.

Safety meetings are held during working hours every other week, with all personnel present; general discussions concerned with stressing safe conduct and procedure for each job in the mine take place. Safety rules are made at these meetings, such as the following:

No rides on trucks.

Smoking not allowed within 50 feet of the face being loaded with explosive.

Never use anything but wood to tamp holes.

Never go back to a face that misfires until told to do so by supervisor.

Walk in haulageways on side facing oncoming trucks.

Be alert. A rock can become loose and fall from the wall as readily as from the roof.

Never put production above safety.

A National Safety Council Trophy (plaque) awarded to the Sunbright plant is circulated at 4-month intervals to the group with the best safety record, based on the fewest man-hours lost due to accidents. The mine organization is determined to hold this plaque permanently.

A first-aid kit is kept in the underground lunchroom. Another kit, including other supplies, blankets, splints, and a basket stretcher, are stored in the mine office on the surface.

Safety improvements to equipment at the mine include the design and installation of a metal canopy on the Jumbo to protect the driller from any falling object and the installation of a converted steam whistle in the air line on the Jumbo to sound a warning to approaching trucks when the Jumbo is moving from one heading to another.

Hard-toed boots are mandatory and are furnished by the company at one half retail cost. All employees and visitors are required to wear hard safety hats while on the property.

Warning signs (circular disks on pipestands) are placed where necessary in the mine and are of the type illustrated in figure 16.

ORGANIZATION

The mine and plant are operated as two separate units. The mine organization, headed by the mine superintendent, is responsible to the plant manager for maintaining the required production of raw limestone through the crushing plant to storage.

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The mine superintendent is assisted by a foreman capable of caring for operational details and a mining engineer whose principal duties are providing survey lines for development headings, mapping the mine (including accessible cavern openings), supervising sampling, compiling cost and production data, estimating ore reserves, solving technical problems, and substituting for the mine superintendent in case of absence.

Although the mine organization is small, complete engineering, production, and cost records are maintained. Accounting reports necessary for mining operations are compiled at the plant's general accounting office.

Mechanical work, including overhaul, replacement of parts, and major repairs, is done as requested by the plant shops, under supervision of a master mechanic.

COMPANY BENEFITS TO EMPLOYEES

In addition to the plantwide bonus system at present in force and vacation with pay, employees receive benefits other than Social Security and Compensation Insurance, as required by law. Wholly borne by the company is complete hospitalization for employees' families, as well as sickness and health benefits to employees for a period of 30 weeks. While in the employ of the company, each person is covered by a $2,000 paid life-insurance policy. A retirement-fund program has been initiated without cost to the employee for all employees who have reached the age of 30 years and have completed 3 years of continuous service. The benefit formula is established as 0.5 percent for the first $4,200 of base earnings and 1 percent of all over $4,200 per year. The formula applies to base earnings for each year after eligibility requirements have been completed. The sum of the many years' calculation equals the total of the annual retirement of the employee. Normal retirement is at 65, but an employee may retire with the consent of the company after his 55th birthday, provided he has completed 18 years of continuous service.

The Chambers scholarship fund was established in 1955 to finance college education for children of Foote Mineral Co. employees; it provides opportunities without limit as to any specific number of individuals. Three young people from families of employees at the Sunbright plant are among those at present receiving the benefits of higher education.

COSTS

To simplify reporting and cost accounting, only two account numbers are alloted for production of limestone. One number covers mining, and the other has been assigned to crushing. No subdivision is provided for reporting time and attendance under the various phases of mining, such as development, mining, and transportation, or for further breakdown in classification such as drilling, blasting, and scaling.

Supervision is prorated between mining and crushing on a ratio of about 2:1, and electric power (not metered) is estimated on an arbitrary basis in proportion to spot check on amperage drawn by equipment over the time period of operation.

All major costs in purchasing contractural service and equipment are depreciated over a period of 5 years, and a monthly charge to production is made in accordance with this policy.

Complete coverage of the average direct cost per ton hauled from the mine, taken over a period of 6 months (July - December 1955), is as follows:

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	Avg. per month
Total from mine ..... tons	17,019
Total to storage pile ..... do.	13,955
Discard ..... percent	18
Days worked	22.1
Average mined per working day ... tons	770

Unit cost per ton	Cost per ton	Cumulative cost
Mining		
Labor	$0.363	
Supervision	.031	
Maintenance (shop labor)	.023	
Explosives	.133	
Drill steel, bits	.057	
Electric power	.022	
Rolling-stock repair parts (loading and hauling)	.042	
Motor fuel	.017	
Supplies, miscellaneous	.042	
Rentals of equipment	.003	$0.733
Crushing		
Labor	$0.070	
Maintenance (shop labor)	.008	
Supervision	.016	
Electric power	.033	
Repair parts	.015	
Supplies (miscellaneous)	.004	$0.879
Depreciation of:		
Diamond-drill exploration	$0.003	
Mine equipment	.163	
Crusher equipment	.166	$1.211
Total direct cost per ton, including depreciation of equipment ...	$1.211	

The unit costs, as given in the above tabulation, include the 18 percent of production for the period discarded as waste at the crusher and in the mine on a ratio of about 2:1 for the crusher and the mine, respectively. To calculate the cost per ton of crushed stone to storage pile, add 22 percent to the given costs.

It is anticipated that some costs will be reduced when a larger primary crusher is installed and present trucks are replaced with vehicles of larger capacity.

Improvement in the physical structure noticeable as the mine workings extend deeper into the limestone bed may result in less waste to be handled from roof overbreak and contamination by silt and clay.

The mine and crusher operation has the advantage of location. It is unnecessary to provide separate shops for mechanical and electrical maintenance and repair. Such services are obtained as required, and no overhead is charged against shop orders.

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TABLE 1. - Summary of costs

Name or number of mine Sunbright mine Period covered December 1955

Tons from mine during period 16,867[1/]

Mining method Room-and-pillar and benching floors

1. Direct underground costs per ton ore produced and hauled from mine:

	1 Labor	2 Super-vision	3 Compressed-air drills and steel	4 Power cost	5 Explo-sives	6 Tim-ber	7 Other supplies and repairs	8 Total
(a) Mining	$0.114	$0.021	$0.101	$0.004	$0.132	-	$0.001	$0.373
(b) Transportation (underground)	.155	.028	-	-	-	-	.134	.317
(c) General underground expense	.034	.006	-	.001	-	-	.014	.055
Surface expense (directly applicable to underground operation)				None				
Total	.303	.055	.101	.005	.132		.149	.745

Notes:

1/ Includes 4,553 tons of material discarded by sorting in mine and fines discarded from crusher screens.

General:

1. Includes all labor employed at the mine. No mine labor is directly employed on the surface except for operation of the crushing plant.

   (a) Includes drillers, helpers, and blasters employed at tunneling and benching.
   (b) Includes Eimco-loader operation, pitman, and truck drivers.
   (c) Includes estimated one half time of wagon-drill operators. When not mining, they are engaged at miscellaneous work, such as building or repairing brattices, sampling, surfacing roadways, scaling, roof bolting, etc.

2. Supervision includes salaries and wages of foreman, engineers, and superintendent properly chargeable to underground operations, distributed in proportion to labor costs.

3. Compressed-air drills and steel includes power cost for air compression, steel and bit cost, and "shop-order" charge to air line.

4. Power cost is direct estimate for ventilation charged to mining, and lighting is charged to general underground expense.

5. Explosives directly charged to mining.

6. No timber is used for roof support.

7. "Other supplies" includes repair parts, shop labor, brattice cloth, aluminum pipe for scaling bars, grease, engineering supplies, etc.

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TABLE 2. - Summary of costs, in units of labor, power, and supplies

Name of mine Sunbright Period covered December 1955

Tons from mine 16,867[1]

Mining method Room-and-pillar and benching floors

A. Labor (man-hours per ton)	Total mining
Breaking (drilling and blasting)	0.073
Shovel loading	.030
Haulage	.060
Supervision	.031
General	.022
Total labor underground[2]	.216
Avg. tons per man per shift[2]	37.1
Labor, percent of total cost[2]	48.1
Avg. tons per man-shift on surface properly chargeable to underground operation (shop labor)	865

B. Power and supplies	
Explosives (lb. per ton) 45 percent bulk strength, semigelatin dynamite	0.40
Approx. total power (in kw.-hr. per ton)	
(1) Air compression	2.173
(2) Ventilation	.502
(3) Lighting	.111
Other supplies and shop repairs, percent of total supplies and power	38.7
Supplies, repairs and power, percent of total cost	51.9

1/ Includes 4,553 tons of material discarded by sorting in mine and fines discarded at crusher screens.

2/ Including supervision.

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TABLE 3. - Detail of direct costs in units of labor, power and supplies, and dollars, advancing headings, December 1955

All mining with Jumbo drill

	Units per foot	Dollars per foot
Size of excavations average 20.3 by 38.2 ft.		
Physical properties of rock: Hard, firm, brittle.		
A. Labor (man-hours per foot)		
Breaking (drilling and blasting)	3.26	5.13
Mucking (mechanical loading)	1.71	3.17
Haulage	3.41	5.69
Supervision	1.32	3.54
Total labor	9.70	17.53
Feet per 8-hr. drilling shift	11.9	
B. Power and supplies (per foot)		
Explosives (lb. per foot)	24.33	8.06
Total power, estimate:		
1. Air compression ... kw.-hr.	124.5	1.00
2. Ventilation ... do...	28.7	.23
3. Lighting ... do...	6.4	.05
Other supplies, including shop labor on repairs.		13.13
C. Labor (percent), total cost	43.8	
Power and supplies (percent)	56.2	
Total cost		40.00

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